	Type	Hits	Search Text	DBs
1	BRS	1	(variable near power near amplif$6) and 455/552.1.ccls.	USPAT; US-PGPUB; EPO; JPO; DERWENT
2	BRS	5	(variable near power near amplif$8) and 455/522.ccls.	USPAT; US-PGPUB; EPO; JPO; DERWENT
3	BRS	10	modulator and (power near control$4) and (variable near power near amplif$6) and 455/$.ccls.	USPAT; US-PGPUB; EPO; JPO; DERWENT
4	BRS	14	(digital near analog or (d/a)) and (power near control$4) and (variable near power near amplif$6) and 455/$.ccls.	USPAT; US-PGPUB; EPO; JPO; DERWENT
5	BRS	15	((intermediate adj frequency) and (power near control$4) and (variable near power near amplif$6) and 455/$.ccls.) or ((digital near analog) and (power near control$4) and (variable near power near amplif$6) and 455/$.ccls.) and (digital near analog or (d/a)) and (power near control$4) and (variable near power near amplif$6) and 455/$.ccls.	USPAT; US-PGPUB; EPO; JPO; DERWENT
6	BRS	37	(variable near power near amplif$8) and 330/$.ccls.	USPAT; US-PGPUB; EPO; JPO; DERWENT
7	BRS	13	fuzzy and ("819895" or "459627" or "5737697").ap. or ("883250" or "40584" or "388894").pn.	USPAT; US-PGPUB; EPO; JPO; DERWENT

"DO NOT MAIL"

"EXAMINER'S NOTES SEARCH ONLY"

US006411825B1

(12) **United States Patent**
Csapo et al.

(10) **Patent No.: US 6,411,825 B1**
(45) **Date of Patent: Jun. 25, 2002**

(54) **DISTRIBUTED ARCHITECTURE FOR A BASE STATION TRANSCEIVER SUBSYSTEM**

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(73) Assignee: **Samsung Electronics, Co., Ltd.** (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/311,548**

(22) Filed: **May 13, 1999**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/149,168, filed on Sep. 8, 1998.
(60) Provisional application No. 60/058,228, filed on Sep. 9, 1997.

(51) **Int. Cl.**^{7} **H04Q 7/155**
(52) **U.S. Cl.** **455/561**; 455/88; 455/550
(58) **Field of Search** 455/561, 88, 550, 455/552, 553, 269, 272

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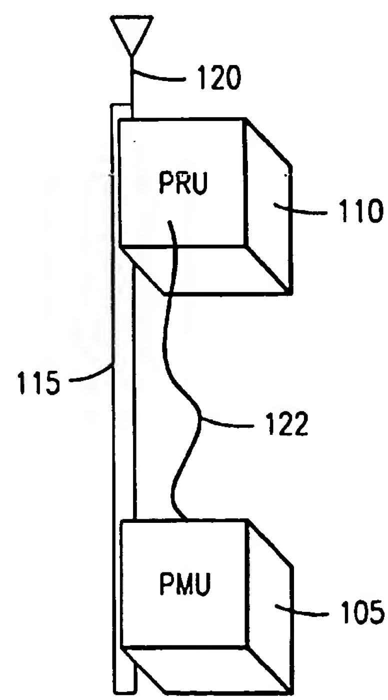
Primary Examiner—Daniel Hunter
Assistant Examiner—Thuan T. Nguyen
(74) *Attorney, Agent, or Firm*—John C. Han

(57) **ABSTRACT**

A telecommunication base station transceiver subsystem that can be easily configured to provide single or multi-carrier frequency service. Capacity is increased and diversity reception is maintained from a single to a dual frequency system without the need for additional antennas. The base station is divided into a main unit and a radio unit such that the radio unit is positioned proximate to the antennas and the main unit is remotely located from the radio unit. Furthermore, a single base station transceiver can provide service via multiple wireless protocols, such as CDMA, TDMA, GSM or Analog. The base station transceiver can also operate on various transmit/receive frequencies as well as variable transmit power settings.

17 Claims, 10 Drawing Sheets



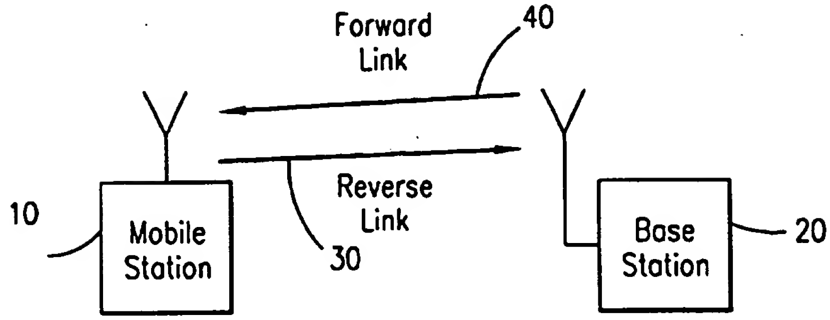


FIG. 1 (Prior Art)

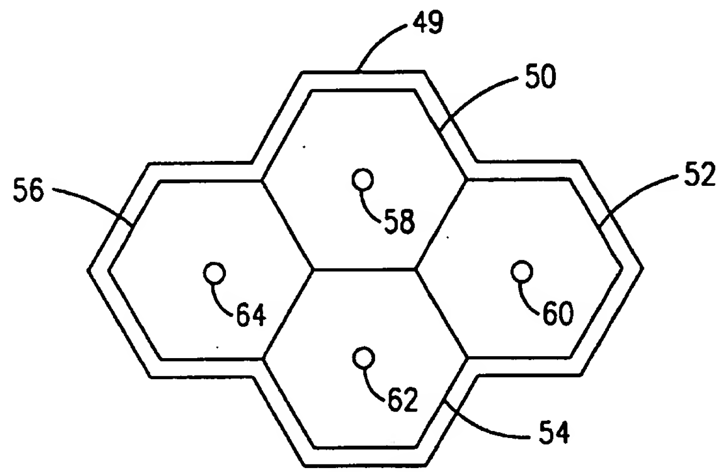


FIG. 2 (Prior Art)

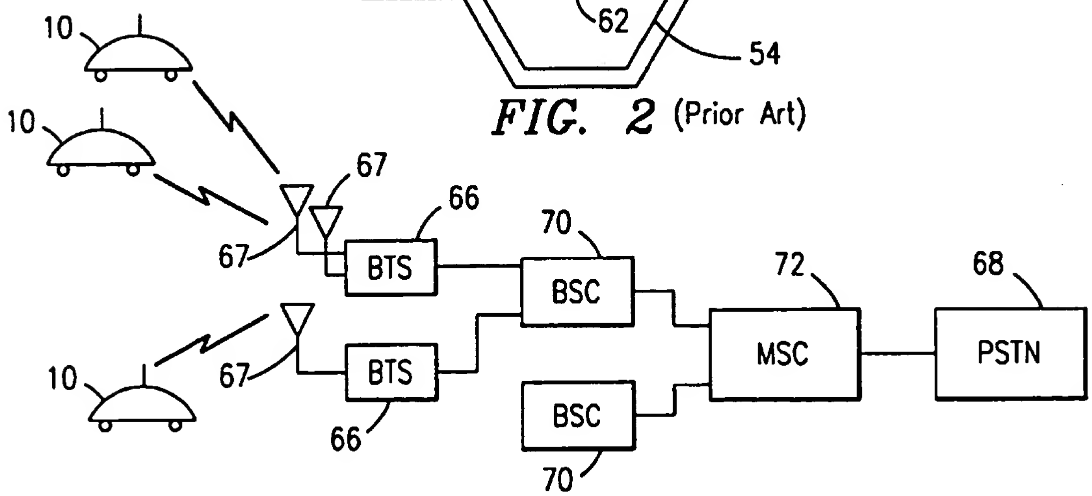


FIG. 3 (Prior Art)

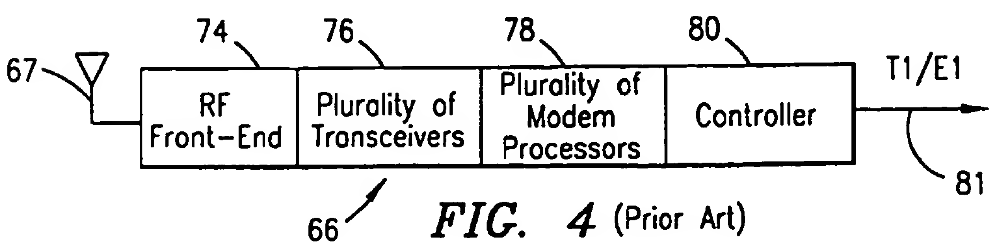


FIG. 4 (Prior Art)

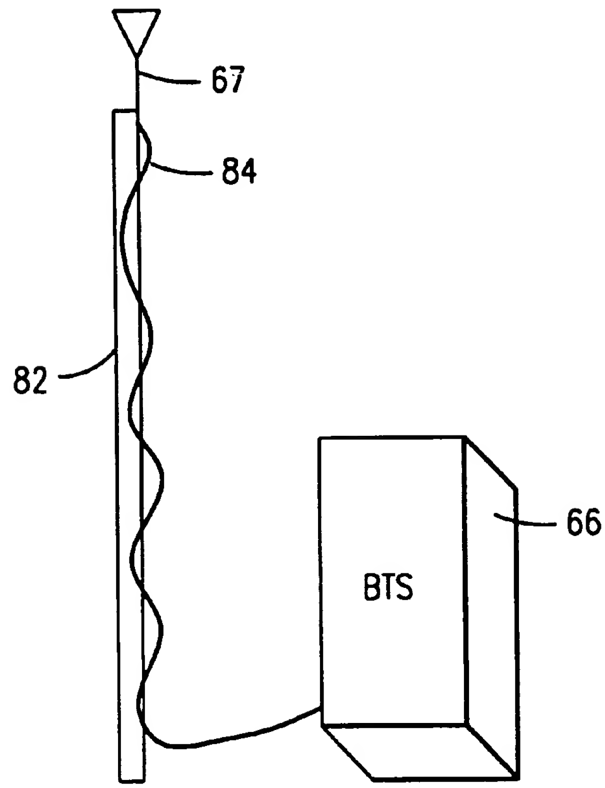


FIG. 5 (Prior Art)

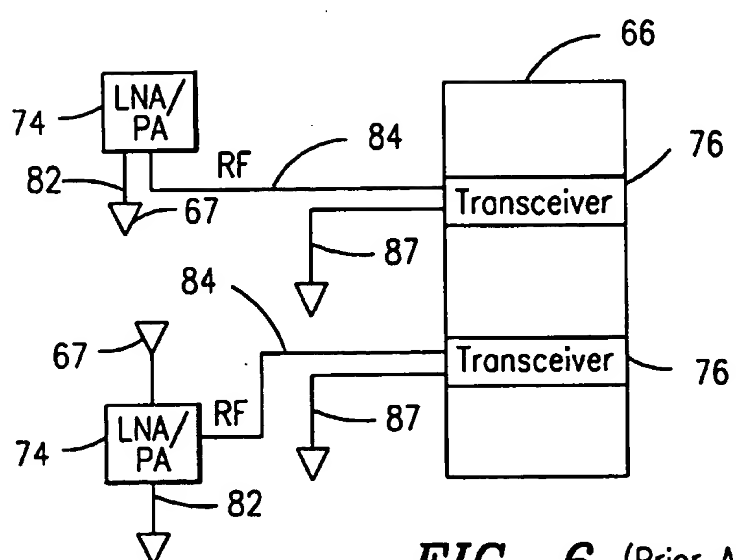


FIG. 6 (Prior Art)

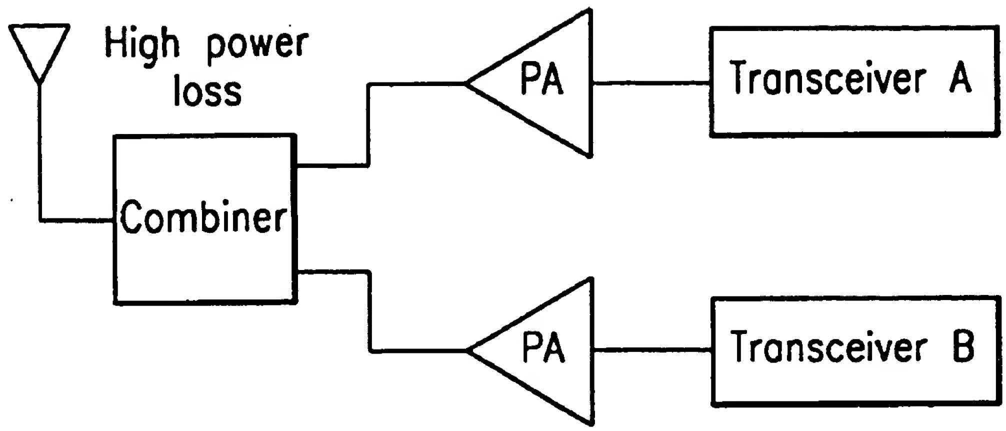


FIG. 7 (Prior Art)

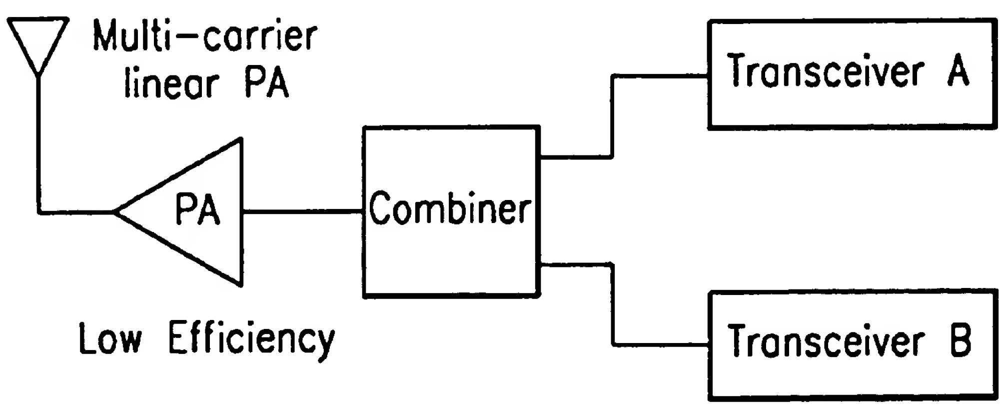


FIG. 8 (Prior Art)

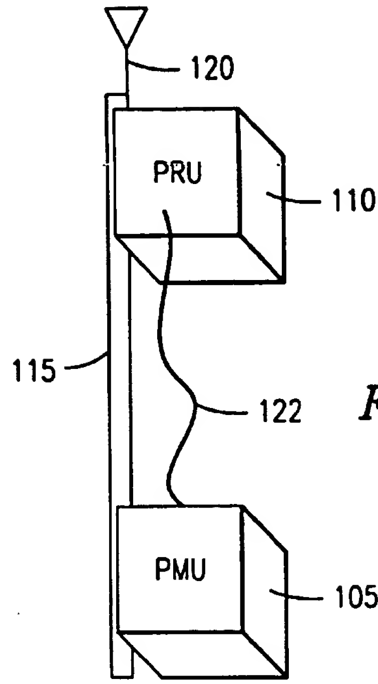


FIG. 9

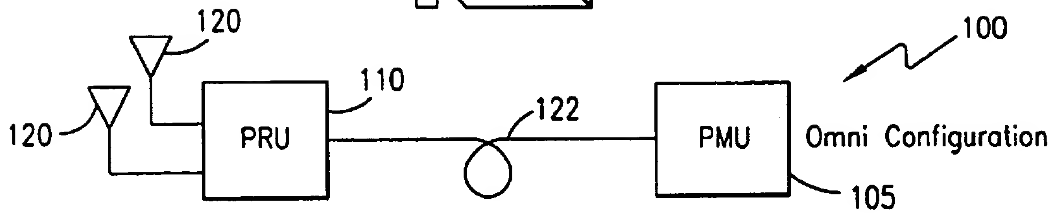


FIG. 10

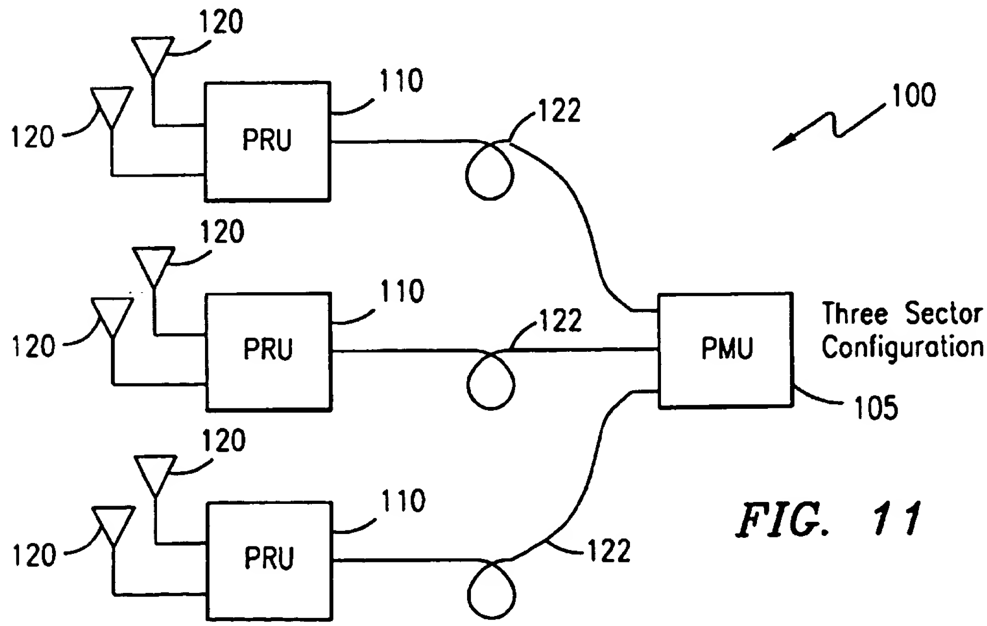


FIG. 11

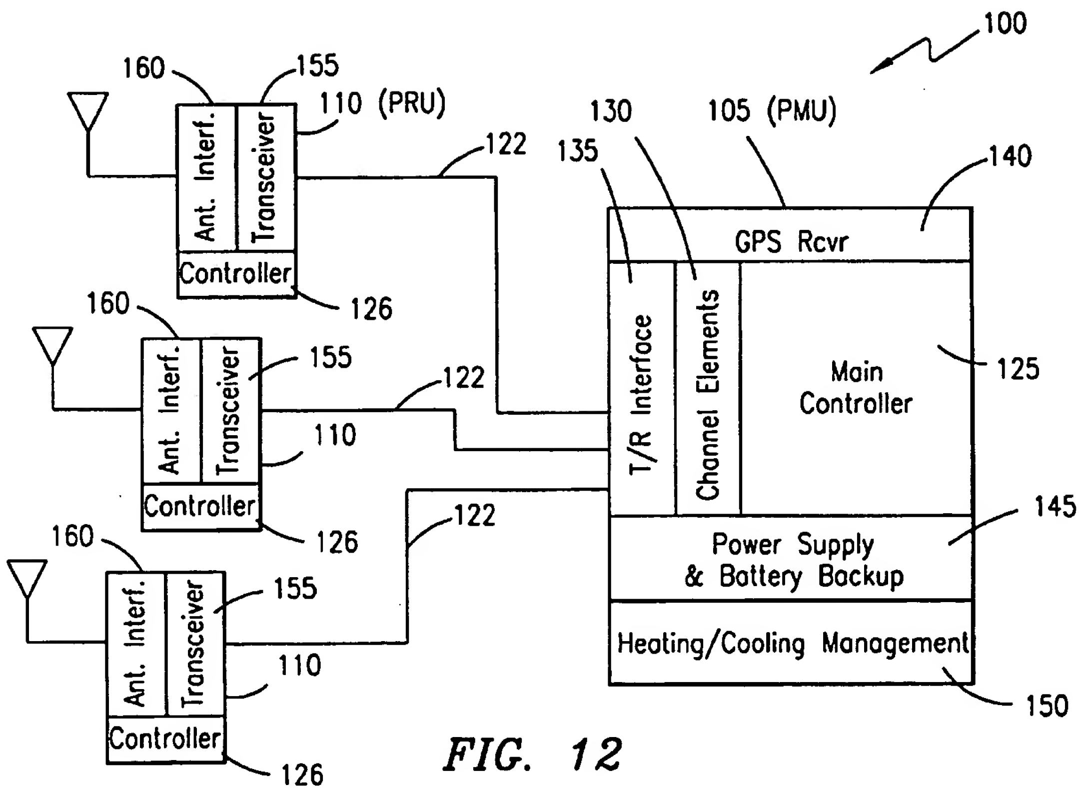

100
160
155
110 (PRU)
Ant. Interf.
Transceiver
Controller
126
122
130
105 (PMU)
135
140
GPS Rcvr
T/R Interface
Channel Elements
Main Controller
125
160
155
122
110
126
Power Supply & Battery Backup
145
Heating/Cooling Management
150
160
155
122
110
126

FIG. 12

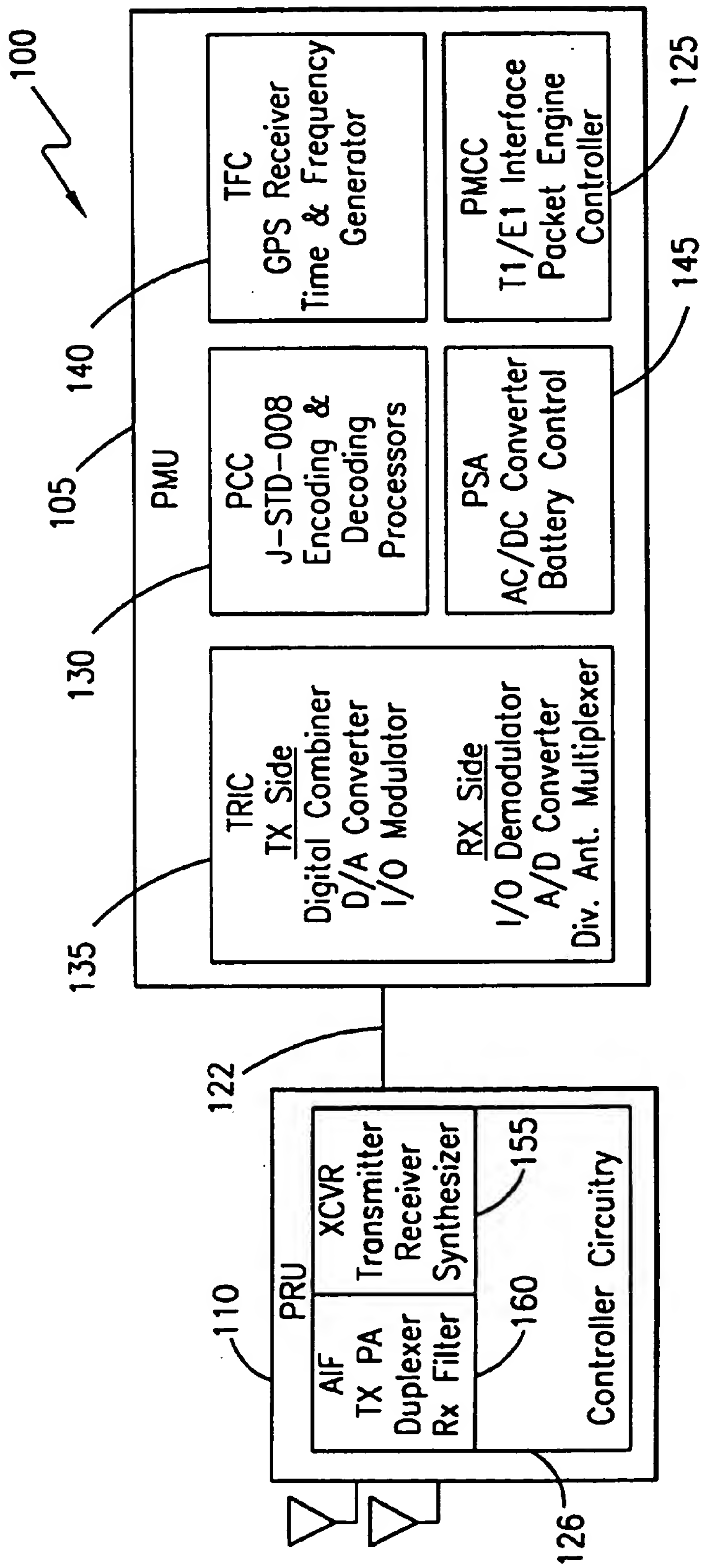

100
105
PMU
140
TFC
GPS Receiver
Time & Frequency
Generator
PMCC
T1/E1 Interface
Packet Engine
Controller
125
130
PCC
J-STD-008
Encoding &
Decoding
Processors
PSA
AC/DC Converter
Battery Control
145
135
TRIC
TX Side
Digital Combiner
D/A Converter
I/O Modulator
RX Side
I/O Demodulator
A/D Converter
Div. Ant. Multiplexer
122
110
PRU
XCVR
Transmitter
Receiver
Synthesizer
155
AIF
TX PA
Duplexer
Rx Filter
160
Controller Circuitry
126

FIG. 13

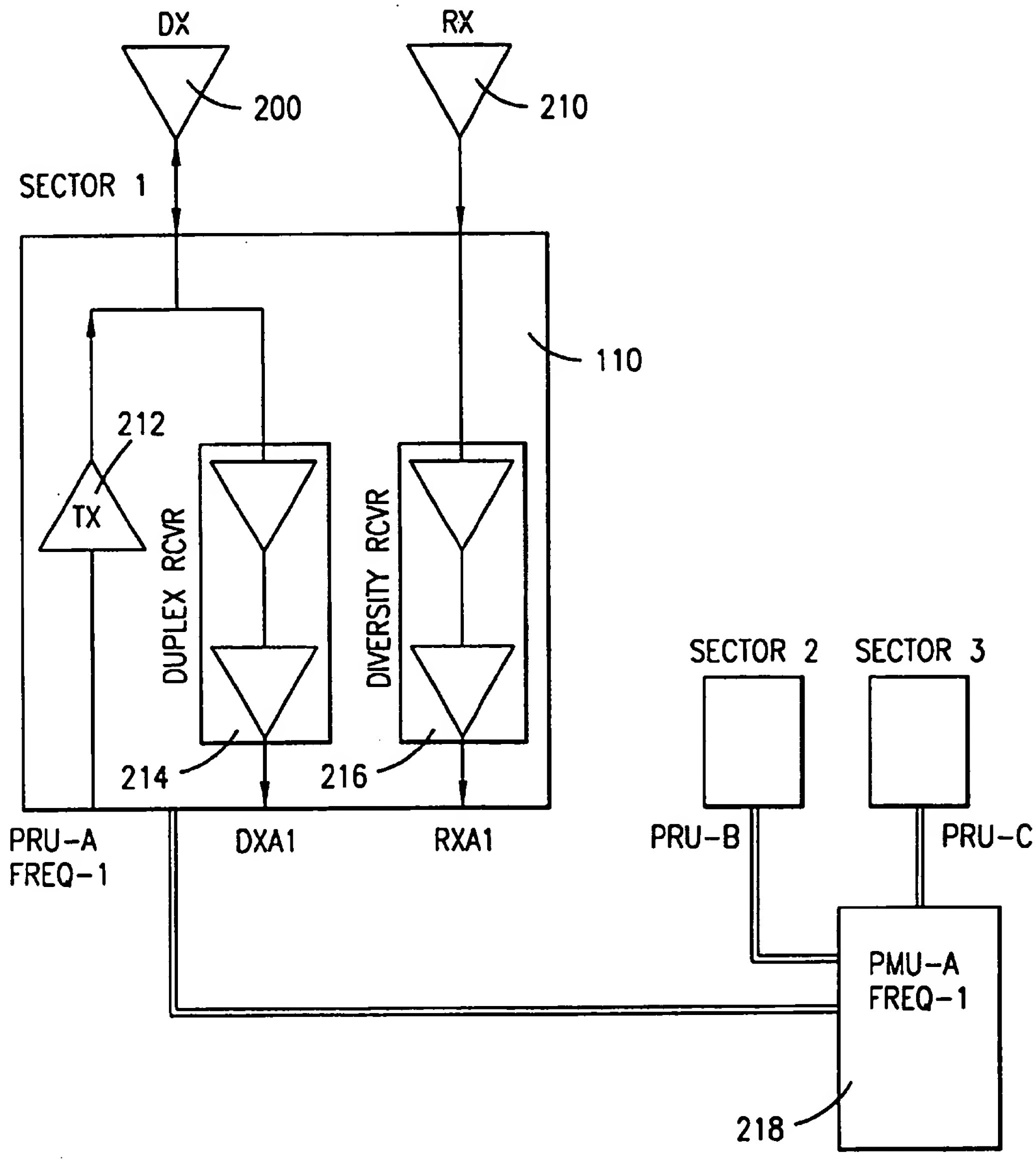
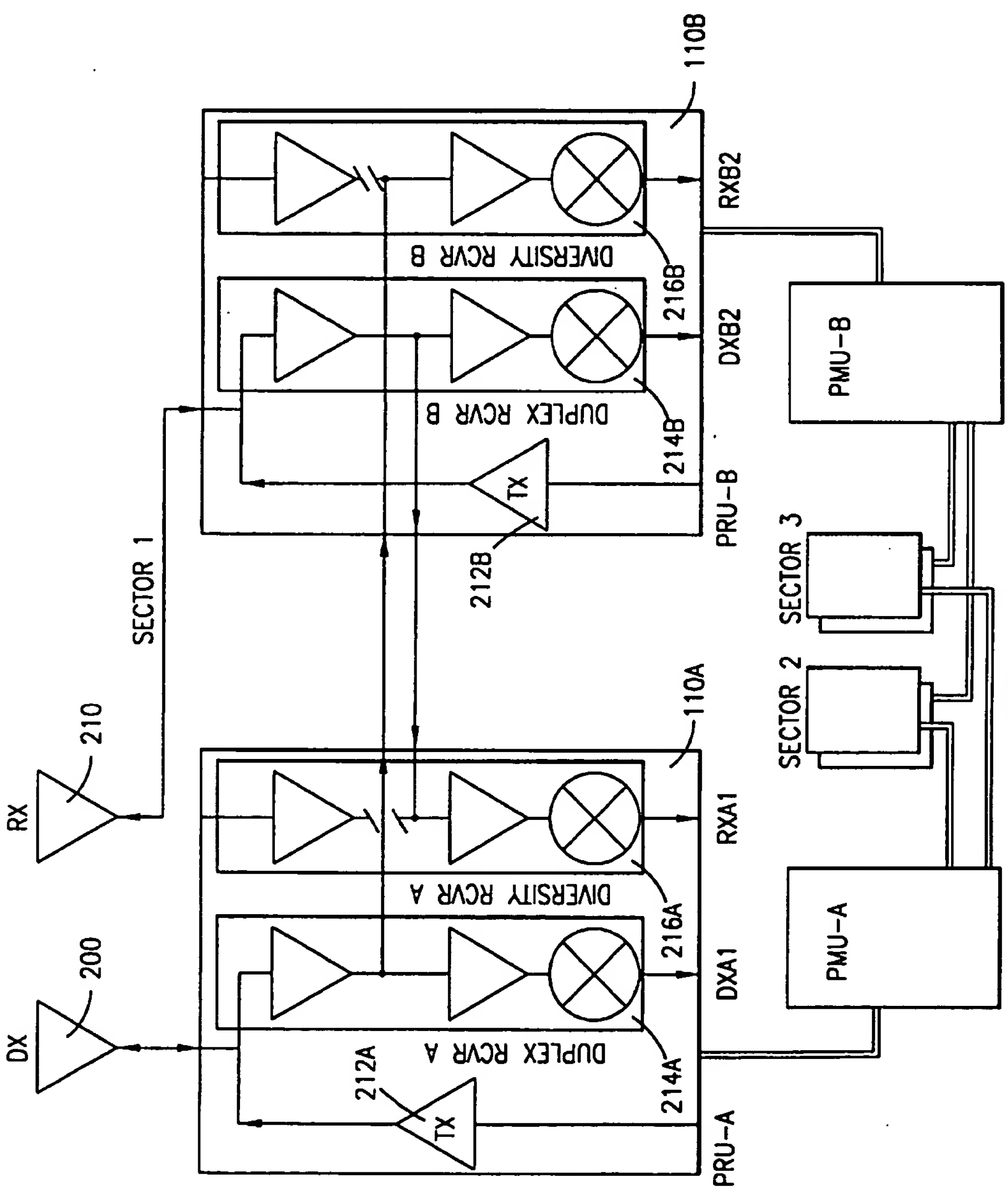

DX
RX
200
210
SECTOR 1
110
212
TX
DUPLEX RCVR
DIVERSITY RCVR
SECTOR 2
SECTOR 3
214
216
PRU-A
FREQ-1
DXA1
RXA1
PRU-B
PRU-C
PMU-A
FREQ-1
218

FIG. 14



DX
200
RX
210
SECTOR 1
110A
110B
DUPLEX RCVR A
DIVERSITY RCVR A
DUPLEX RCVR B
DIVERSITY RCVR B
TX
TX
212A
212B
214A
214B
216A
216B
PRU-A
PRU-B
DXA1
RXA1
DXB2
RXB2
PMU-A
PMU-B
SECTOR 2
SECTOR 3

FIG. 15

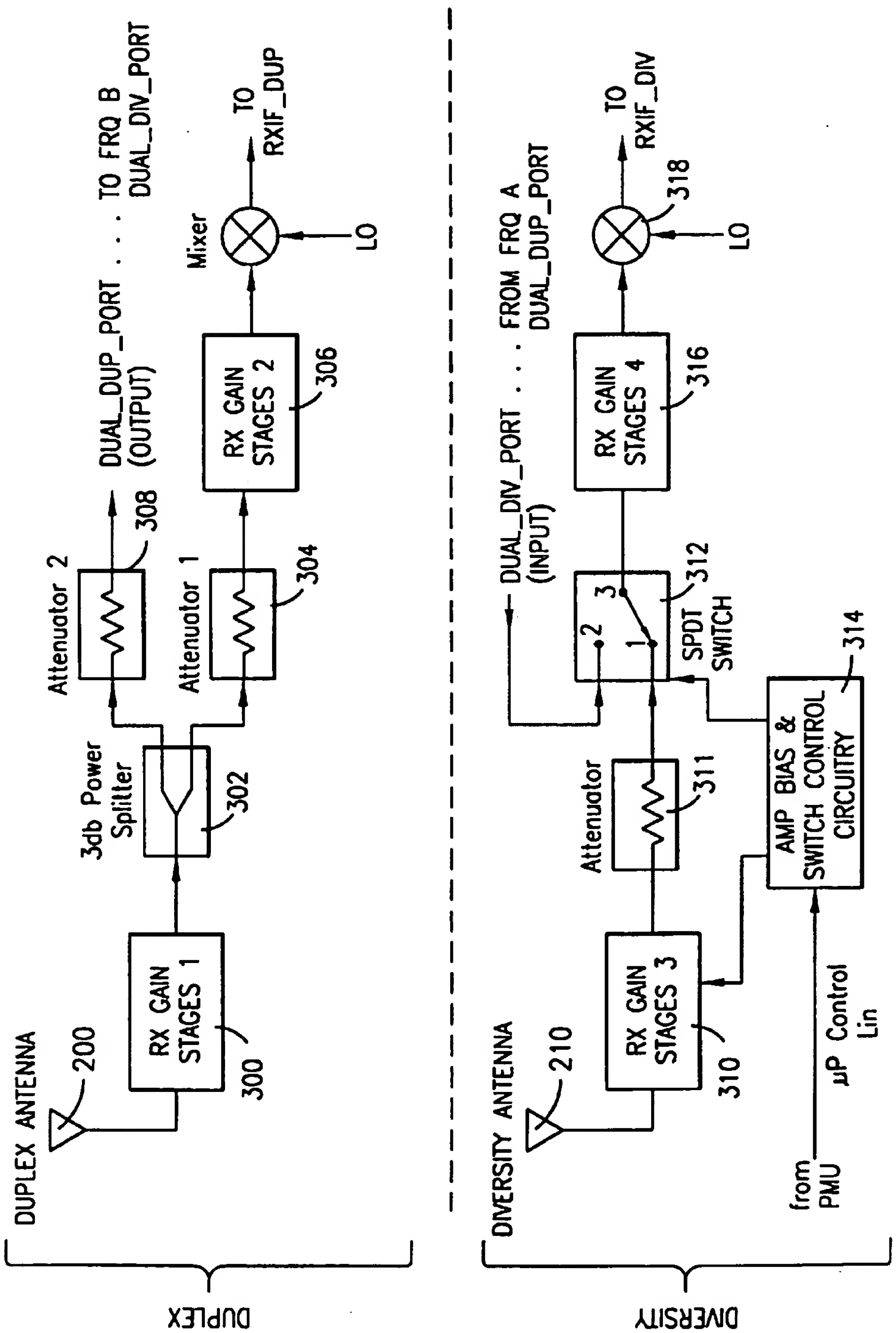
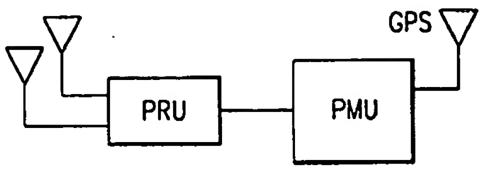
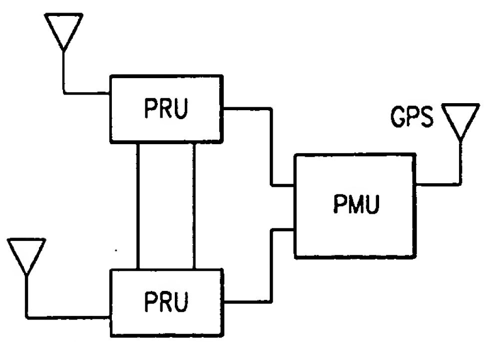

DUPLEX
DUPLEX ANTENNA
200
RX GAIN STAGES 1
300
3db Power Splitter
302
Attenuator 1
304
Attenuator 2
308
DUAL_DUP_PORT (OUTPUT)
. . . TO FRQ B DUAL_DIV_PORT
RX GAIN STAGES 2
306
Mixer
LO
TO RXIF_DUP
DIVERSITY
DIVERSITY ANTENNA
210
RX GAIN STAGES 3
310
Attenuator
311
AMP BIAS & SWITCH CONTROL CIRCUITRY
314
from PMU
µP Control Lin
SPDT SWITCH
312
1
2
3
DUAL_DIV_PORT (INPUT)
. . . FROM FRQ A DUAL_DUP_PORT
RX GAIN STAGES 4
316
318
LO
TO RXIF_DIV

FIG. 16



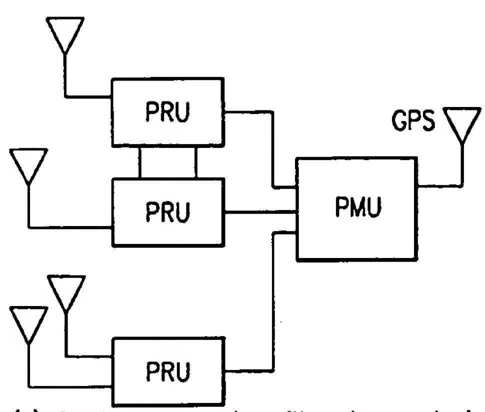
(a) Omni, single frequency with diversity antennas

FIG. 17a



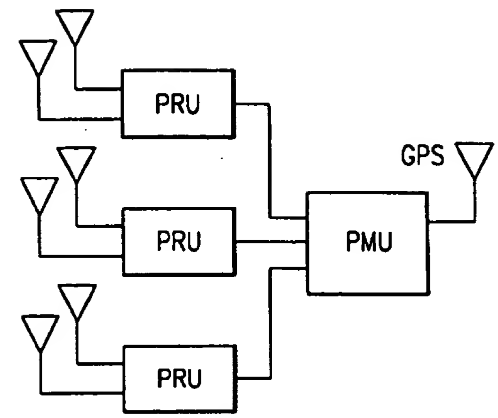
(b) Omni, dual frequency with antenna-sharing

FIG. 17b



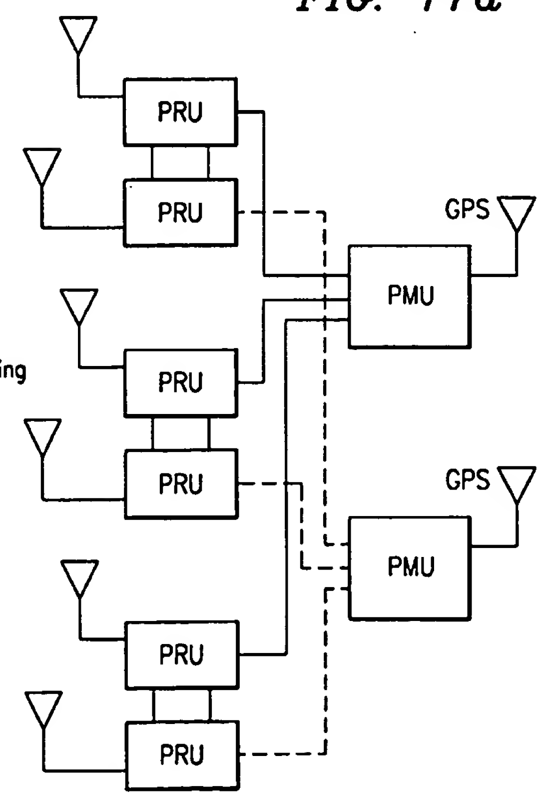
(c) Omni, three carrier with antenna-sharing on three frequencies

FIG. 17c



(d) Three-sector, single frequency with no antenna sharing

FIG. 17d



(e) Omni, multi-carrier with antenna-sharing on pairs or frequencies

FIG. 17e

DISTRIBUTED ARCHITECTURE FOR A BASE STATION TRANSCEIVER SUBSYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of Ser. No. 09/149,168, filed Sep. 8, 1998, which claims the benefit of U.S. Provisional Application No. 60/058,228, filed Sep. 9, 1997.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to wireless communication systems and, more particularly, to base station transceiver subsystems used in a Code Division Multiple Access (CDMA) network or other digital and analog telecommunication systems.

2. Description of Related Art

FIG. 1 (prior art) is a block-flow diagram which graphically represents a wireless communication system. From FIG. 1 it is seen that a basic wireless communication system comprises a mobile station 10, a base station 20, a reverse link 30, which represents the electromagnetic wave communication link transmitted from mobile station 10 to base station 20, and a forward link 40 which represents the electromagnetic wave communication link transmitted from base station 20 to mobile station 10.

FIG. 2 (prior art) shows a cell grid and cell sites. In a wireless communication system based on the general cellular principle, a service area 49 is divided geographically, into a number of small areas 50, 52, 54, 56 called "cells." In each cell there is a cell site 58, 60, 62, 64 where radio equipment known as a Base Station Transceiver Subsystem (BTS) is installed. Multiple cell layouts such as macro cells, micro cells, and Pico cells can be provided within a particular geographical area to effect hierarchical coverage (where macro cells provide the largest coverage and Pico cells the smallest). Pico cells may be used to provide coverage inside buildings, to cover a special area (campus, stadium, airport and shopping mall), to temporarily cover for special events or areas hit by natural disasters, to cover outlying remote locations, to supplement macro or mini cells with hole-filling, or to enhance the capacity of hot spots. FIG. 3 (prior art) is a block diagram of a wireless system network connected to a land line Public Switched Telephone Network (PSTN) 68. As shown in FIG. 3, a BTS 66 provides a link to mobile subscribers or (mobile stations) 10. Each BTS 66 typically may include two or more antennas 67, which may be omni antennas or directional antennas. Omni antenna configurations provide 360° of coverage, whereas directional antennas provide less than 360° of coverage across an area known as a sector. For example, there may be two, three or more sectors in a typical directional configuration such that each sector of a two sector configuration generally provides 180° of coverage and each sector of a three sector configuration generally provides 120° of coverage, etc. For satisfactory reception and transmission, each sector typically requires at least two antennas for diversity reception.

Continuing with the description of FIG. 3, each BTS 66 is coupled to a Base Station Controller (BSC) 70 (multiple BTSs 66 may be coupled to a single BSC 70). Likewise, each BSC 70 is coupled to a Mobile Switching Center (MSC) 72 and the MSC 72 is in turn coupled to a PSTN 68.

FIG. 4 (prior art) is a functional block diagram of a BTS. As shown in FIG. 4, a conventional BTS 66 typically comprises four major functional blocks for each sector of coverage: an RF front-end 74, a plurality of transceivers 76, a plurality of modem processors 78, and a controller 80. Controller 80 interfaces with a BSC 70 over a T1 or E1 line 81, and the RF front-end 74 is connected to the antennas 67 which are typically mounted at the top of a tower or pole 82 as represented in FIG. 5 (prior art), where FIG. 5 illustrates an outdoor and ground based BTS coupled to a tower topped mounted antenna.

In a typical system, the four major functional blocks of the BTS 66, shown in FIG. 4, are contained in one physical cabinet or housing which is in close proximity to a pole (or tower) 82 at ground level. Long coaxial cables 84 are then run to the top of the pole 82 where the antennas 67 are mounted. The cable length typically varies from 50 to 200 feet, depending on various installation scenarios. Cables of these lengths suffer from undesirable power losses. Accordingly, thick coaxial cable diameters of approximately ¾ to 1½ inches are used to minimize the cable power loss, which is typically about 2 to 4 dB. Minimizing these power losses is important because such losses in the cables degrade the receiver sensitivity and reduce transmission power.

FIG. 5 depicts a prior art BTS unit 66 connected via a long length of cable 84 to an antenna 67 at the top of a supporting structure 82. FIG. 6 (prior art) is a block diagram of yet another known BTS architecture where a tower top mounted RF front-end module consists of a Low Noise Amp (LNA) and a Power Amp (PA) 74 (hereinafter LNA/PA unit 74). The cable power loss in this architecture is not as critical as in the previous mentioned architecture because the power loss can be made up with additional amplification. However, there is still a need to use rather thick cables due to the signals between the LNA/PA unit 74 and the transceiver 76 in the BTS 66 are high frequency/radio-frequency (RF) signals. Other problems are associated with transmitted RF signals between the LNA/PA unit 74 and the BTS 66, such as power losses, system noise, and mechanical clutter. Furthermore additional complex circuitry either or both in the RF front-end module and the transceiver may be required to automatically compensate for the wide range of cable losses that arise in different installation scenarios due to varying cable lengths. Such problems get more severe as the operating RF Frequencies are allocated in the increasingly higher frequency bands. This is the case for personal communications systems.

In other words, as the length of a cable 84 increases, or as the frequency transmitted through a cable 84 increases, power losses between the LNA/PA unit 74 and the ETS 66 increase. Thus, the long cables 84 used to connect the LNA/PA unit 74 to the BTSs 66 (often in excess of 150 feet, sometimes even exceeding 300 feet) introduce large power losses. For example, a 100 W power amplifier in a base station transceiver unit transmits only 50 W of power at the antenna when there is a 3 dB loss in the cable. Power losses in the cable work against reception as well, reducing the ability of the receiver to detect received signals. Also, with Personal Communication Systems (PCS) operating at high frequencies, the power loss in the cable 84 running between the LNA/PA unit 74 and the transceiver 76 in the BTS 66 increases. Thus, RF cable losses incurred on both the transmit and receive paths result in poorer than desired transmission efficiency and lower than desired receiver sensitivity, making the use of relatively thick (high conductance) coaxial cables necessary to minimize loss.

Generally, in a wireless environment, wherein radio frequencies are transmitted through air, interferences are inevitable. That is, unless a transmitting antenna is directly in the

line-of-site of the receiving antenna and no obstacles, such as trees, buildings, rock formations, water towers, etc., are in the way, then reflections will cause fading and multipath signals. In order to minimize the effects of fading and multipath, diversity receivers can be used increase the carrier-to-noise ratio (and/or Eb/No. A diversity receiver requires its own antenna. Thus, for each transmission frequency two antennas are used on the receiving side. One antenna is a transmit/receive antenna and the second antenna is used for a diversity receiver which is utilized to overcome some of the fading and multi-path problems.

In some cell sites where the communication capacity is high, there is a need to transmit more than one RF carrier signal. The transmission of multiple RF carriers per sector requires a corresponding number of transmit antennas per sector. Additional receiving antennas are also required especially if diversity receivers are utilized in the system. Increasing the number of antennas creates an "eye-sore" for the public and is not desirable.

A conventional technique for reducing the number of transmit antennas required for multiple RF carrier transmission are shown in FIGS. **7** and **8**.

In FIG. **7** (prior art) the carriers are combined with a high power combiner. In FIG. **8** (prior art) the carriers are combined at low power and then the combined signal is amplified with a multi-carrier power amplifier.

Neither design is suitable for use in a compact BTS system due to high power loss in the combiners and the inability to provide diversity reception.

What is needed is a compact BTS system that can be adapted to handle multiple transmit and receive frequencies, multiple sector configurations, multiple wireless communication protocols, and be able to transmit signals at a variety of power levels for different types of cells (eg. macro-, micro-, pico-) without increasing the number of antennas significantly or substantially decreasing the overall performance of the system.

SUMMARY OF THE INVENTION

The present invention provides a BTS wherein a radio unit (RU) is located proximate to the antenna mounting location. A main unit (MU) is connected to and remotely located from the RU. One or more antennas are coupled to the RU. There can be a plurality of RUs connected to a single MU. The plurality of RUs may operate on the same or different frequencies, the same or different transmit power, the same or different wireless communication protocols.

An object of the exemplary embodiment of the present invention minimizes the number of antennas required for multiple frequency, multiple communication protocol, or variable transmit power BTS system.

Another object of the present exemplary BTS system allows for two RUs to be connected together to thereby increase the number of operating frequencies, or communication protocols, while maintaining transmission power level without increasing the number of antennas.

Another object of the present invention is to increase call capacity of a BTS without increasing the number of antennas for a cell, thereby minimizing the cost of increasing the call capacity.

Another object of the present invention is to transmit and receive two frequencies or wireless protocols with two antennas and maintain diversity reception. The diversity receiver helps to minimize the effect of fading and multipath.

There are many advantages to this exemplary architecture and some of them are as follows:

A compact size RU is provided which can be easily mounted close to the antennas, whereby cable loss is virtually eliminated. Cable losses degrade the receiver sensitivity and reduce the transmit power. The present invention, thus, allows for a relatively low power PA and provides a transmit power level equivalent to a higher power PA used in a prior art BTS.

The inclusion of the transceiver in the RU allows for a lower frequency interface rather than an RF interface typically used in prior arts, to the MU. The lower frequency interfaces yield lower cable losses, thus allowing the use of inexpensive and small diameter interconnect cables between the RUs and the MU.

The separation of RF elements and dependent elements thereof, also, result in easier adaption of the BTS design to support different RF operating environments or conditions, as in different frequency bands and different transmission power levels, as only the RU needs to be modified, while the same MU is used. This also results in a compact size MU for ease of handling and mounting. This is because less space and weight are required without RF elements installed and, at the same time, less heat is generated in the MU requiring cooling.

This architecture allows a wireless communication provider to provide service via a variety of wireless protocols without the need for a different BTS for each protocol.

This architecture also allows the BTS to be configured to support either omni or sector operations, or to upgrade from omni to sector operations as the traffic demand goes up. This is especially important in CDMA systems where softer handoffs need to be supported between the sectors. For an omni configuration, only one RU is needed. For two or three sector configurations, two and three RUs are needed, respectively. The three RUs can be operated on the same frequency in a three sector configuration or at different frequencies in a three carrier omni configuration.

The present invention also allows the connectivity of another set of three RUs connected to its own MU to the same antennas without the use of a combiner.

By locating the transceiver module in the RU, only low frequency signals need be passed from the transceiver module and the MU. On the receive side, the transceiver module converts a high frequency signal to a low frequency signal, and on the transmit side, the transceiver module converts a low frequency signal from the MU to a high frequency signal for transmission. Thus, only low frequency signals are passed between the RU and MU, minimizing power loss in the cables connecting the two units. This results in the ability to use smaller diameter, less costly cables.

Another advantage to removing the transceiver subsystem from the MU is that the resulting MU is physically much smaller in size and weighs less. This translates into easier installation and maintenance, as well as into flexibility in meeting the technical demands of a challenging operating assignment or challenging environmental considerations. In addition, smaller size and lighter weight BTSs are especially advantageous for Pico-cell applications or micro-cell applications where a greater number of BTSs are required than are needed for macro cell implementations.

Since the entire transmit functionality is contained in the RU, the RU receives only a baseband signal for transmitted data and does all of the up-conversion and amplification at the RU. This eliminates the need for sending RF signals up

to the RU, thus allowing the RU to operate at a higher efficiency than a unit in which the RF signal must travel the length of the pole.

Up-conversion is done in the RU, thus, direct modulation reduces the complexity of the transmit signal line, and provides a significant cost reduction over systems that run a transmit signal up the pole and then up-convert again to RF. Far less RF components are required in the present invention than in the prior art.

Output power calibration can be performed at the factory and the RU can be programmed for usage with any MU. The RU will store full-power settings, as well as reduced power settings, in local memory—thus enabling cell size adjustment from the RU, instead of at the BTS.

Wilting and blossoming attenuation can be accomplished in the RU rather than in the BTS. Also, output power detection is performed in the RU and, more important, can be used to verify the integrity of the entire signal transit path. Previously, in units where the PA is mounted on the pole, the output power attenuation could be detected, but the operator could not determine if the problem was in the PA module or the MU.

System upgrades can be accomplished more easily as entire RUs or MUs can be replaced. In addition, because like elements are configured together, board or device level upgrades are also more easily accomplished than with traditional BTS units.

These and other advantages of the present invention will become apparent to one of ordinary skill in the art after consideration of the figures and detailed description which follows hereinafter.

BRIEF DESCRIPTION OF THE DRAWING

A more complete understanding of the method and apparatus of the present invention may be had by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

FIG. 1 (prior art) depicts a wireless communication system architecture;

FIG. 2 (prior art) is a graphical representation of a cell grid and cell sites.

FIG. 3 (prior art) is a block diagram of a base station system (BTS) shown connected to a land-line PSTN;

FIG. 4 (prior art) is a functional block diagram of a BTS;

FIG. 5 (prior art) is an illustration of a ground based BTS coupled to a tower top mounted antenna;

FIG. 6 (prior art) is a block diagram of a tower top configuration;

FIG. 7 (prior art) is a block diagram illustrating the combiner method for using one antenna to support multiple transceivers;

FIG. 8 (prior art) is a block diagrams illustrating the combiner/multi-carrier method for using one antenna to support multiple transceivers;

FIG. 9 illustrates a base station system according to an embodiment of the present invention coupled to a pole-mounted antenna;

FIG. 10 is a block diagram illustrating a base station transceiver subsystem architecture according to an embodiment of the present invention for an omni configuration;

FIG. 11 is a block diagram illustrating a base station transceiver subsystem architecture according to an embodiment of the present invention for a three sector configuration;

FIG. 12 is a functional block diagrams of a BTS architecture according to an embodiment of the present invention, with selected subsystems shown;

FIG. 13 is a modular level block diagram of an exemplary BTS;

FIG. 14 depicts an exemplary block diagram of a single or multiple frequency, 3-sector embodiment of the present invention;

FIG. 15 depicts an exemplary block diagram of a dual frequency, 3-sector, antenna sharing embodiment of the present invention;

FIG. 16 depicts a block schematic of the duplex and diversity receiving channels of an exemplary PRU; and

FIGS. 17(*a–e*) depicts a plurality of exemplary embodiment configurations of the present invention.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EXEMPLARY EMBODIMENTS OF THE PRESENT INVENTION

In the description which follows, exemplary preferred embodiments of the invention are described for a Pico base station transceiver subsystem architecture. However, it will be understood that the present invention may be applied to any base station transceiver subsystem architecture in a wireless communication system, including, but not limited to, macro and micro base station transceiver subsystems.

FIG. 9 illustrates the basic idea underlying a base station transceiver subsystem (BTS) architecture according to an exemplary embodiment of the present invention—the BTS is separated into two units, the Pico-BTS Radio Unit **110** and the Pico-BTS Main Unit **105**. In the exemplary system illustrated in FIG. 9, a Pico-BTS comprises the Pico-BTS architecture **100** which is divided into the Pico-BTS Main Unit ("Main Unit System," PMU or MU) **105** which may be located, as shown, at the base of a pole, tower, or other support structure **115**, and the Pico-BTS Radio Unit ("Radio Unit System," PRU or RU) **110**, which transmits and receives signals through at least one pole-mounted antenna **120**, and communicates with the PMU **105** via a plurality of wires **122** which may include a coax cable.

An embodiment of the present invention is illustrated in a high-level block diagram as an omni configuration in FIG. 10. PRU **110** can be distally connected to the PMU via the wires or cables **122**. The distance or separation between the PRU **110** and the PMU **105** can be more than 350 feet (current systems are typically separated by about 150 feet). This is adequate since the PMU **105** is designed to be placed at the bottom of a tower building, pole or other supporting structure **115** and the PRU **110** is to be placed at the top near the antenna(s). To transmit and receive signals, the PRU **110** is shown coupled to one, but typically is coupled to at least two, tower top mounted antennas **120**.

The wires or cables **122** can include optical cabling between the PMU **105** and the PRU **110**. Optical cabling will increase the distance allowable between the PMU and RMU because an optical signal will be less lossy than an electric signal in, for example, a coaxial cable.

FIG. 11 illustrates a BTS architecture according to an exemplary embodiment of the present invention for a three sector configuration. Note that the hardware systems which are required to be duplicated are only duplicated in the PRU **110**. Thus, the PMU is capable of interfacing with 1, 2, 3 or potentially more PRU's.

FIG. 12 is a block diagram illustrating exemplary elements of the PRU **110** and the PMU **105**. As seen the PRU

110 is composed of transceiver module 155 which is coupled to the antenna interface assembly 160. The antenna interface assembly 160 is coupled to the antennas 120. Controller circuitry 126 controls the antenna interface 160 and transceiver 155 portions of the PRU 110. The controller circuitry can control the power output level of the antenna, the carrier frequency used to modulate the communication signal, or can support different control mechanism control mechanisms required by different communication protocols employed by the PRU 110.

The PRU 110 is coupled to the PMU 105 through a set of cables 122 which terminate in the PMU 105 at the Transmit and Receive interface 135 (T/R interface), which is coupled to the channel elements 130. The channel elements 130 are where a CDMA signal or other communication protocols is modulated and demodulated. There are a variety of protocols that could be supported by a single PMU and PRU combination. Such protocols include, but are not limited to CDMA, IS95 (A, B, C, etc.), Wide Band CDMA, IMT-200, CDMA2000, TDMA IS-136, GSM, AMPS analog, NAMPS analog, paging protocols, short message service protocols, and any other cellular or PCS protocols. The PMU 105 may also contain a global positioning receiver 140 which provides accurate clock and frequency signals to a main controller module 125, the channel elements 130, the T/R interface 135, and the PRU(s). Also within the PMU 105 is a power system 145, and a temperature control subsystem 150.

FIG. 13 provides additional detail of the PRU 110 and PMU 105 subsystems. As shown in FIG. 13, each PRU 110 essentially comprises three modules: a transceiver module 155 (XCVR), antenna interface module 160 (AIF) and controller circuitry 126. These modules, however, can be combined into one or more then one module. Accordingly, the antenna interface module 160 may include a transmit power amplifier (PA) which amplifies the signal to a level required for desired cell coverage, two low-noise amplifiers (LNA-not shown) for amplifying received signals to maximize receiver sensitivity, a duplexer module for transmitting and receiving signals to and from a single antenna, and a receiver filter (Rx). The transceiver module 155 may include synthesizer circuitry, transmitter circuitry, and two receiver circuits (it is common to refer to a system's transmitter and receiver circuitry collectively as a "transceiver").

The PRU 110 also includes a controller portion 126 which includes a microprocessor and non-volatile memory to store calibration data and provide real-time temperature operating parameter compensation to the transceiver. Thus, a mobile station or mobile simulator is not needed for calibration, and system calibration in the field is also no longer needed. PRU 110 preferably houses the duplexer and the receive filter in a common cavity. This is essentially three filters (two receive and one transmit) combined into one metallic cavity. By combining the prior art duplexer cavity with the prior art diversity receive cavity, valuable space inside the unit may be used for other circuitry and cost is further reduced.

In the preferred exemplary embodiment, the duplexer/receiver filter cavity of PRU 110 is designed so that the connectors on the filter protrude directly through the cover of the unit, eliminating any coaxial cable bulkhead connectors. This approach requires fewer parts in the unit, again saving valuable space and reducing cost.

An embodiment of the present base station transceiver can provide a large amount of flexibility to the wireless service provider. First of all the transmit power amplifier found in the antenna interface portion 160 can be controlled by the controller circuitry 126 to output various predetermined amounts of power. For example, the transmitter power amp of the exemplary embodiment may be able to transmit at powers ranging from half a Watt to as high as 30 watts or more. Different PRUs could be manufactured to provide varying amounts of transmitter power. One PRU may be designed to transmit from half Watt to 5 Watts. Another PRU may transmit from 1 to 10 Watts. Still yet another PRU embodiment may be able to transmit from 3 to 30 Watts. The amount of output power is controlled by the controlling circuitry 126.

The controlling circuitry may be communicated to via the cables 122 by the main unit 105. Thus, the output transmit power of the PRU 110 can be changed without physical servicing of the PRU 110. Instead a control signal can be sent to the PRU 110 to vary the transmit power. An advantage of being able to actively change the transmit power of a PRU are that the traffic carried by a network of base stations in a cellular style communication network can be balanced. In a downtown portion of a large city there may be a large density of customers in a relatively small area during daytime business hours, but may be a much smaller density of cellular customers in the evening or on weekends, the present exemplary PRU 110 can be set to balance traffic during weekday business hours by transmitting at a lower power to limit its range and pick up the high density of customers. In the evening or on weekends it can be reconfigured to transmit at a higher power to increase the PRU's range and pick up calls within the lower density of customers in the area.

Another way an exemplary embodiment of the present exemplary base station transceiver can provide additional flexibility to a service provider is by providing radio units that can be either programmed or hardwired to transmit and receive at different frequencies. Being able to transmit and receive at multiple frequencies is useful for many reasons. Each additional transmit and receive frequency increases the capacity of the BTS. Utilizing two frequencies doubles the capacity and utilizing three frequencies triples the capacity. Each PRU 110 that is in communication with a PMU 105 can be programmed or hardwired to transmit at a different frequency.

Furthermore, by operating at different frequencies, interference between sectors, adjacent cells and other wireless communication carriers can be minimized. Also, frequency interference between different protocols can be minimized.

The PRU 110 can also be designed to transmit and receive various different protocols. Furthermore, PRUs utilizing different protocols can all be connected to the same PMU 105. Such various protocols include, but are not limited to CDMA, Wide Band CDMA, CDMA2000, IMT-2000, TDMA, GSM, AMPS, NAMPS, Analog protocols, paging protocols, short message service protocols, and other digital protocols.

The PMU 105 may exercise a level of control over the PRU 110. That is, the PMU may be able to control the setting of the transmit power, the frequency, or the protocol that the PRU 110 utilizes. The PMU 105 receives a message via a wireless backbone network or other PSTN requiring a change in the characteristics of the PRU.

The PMU is responsible for the digital termination of a wireless protocol. That is, for example, the PMU handles the landline-to-CDMA or CDMA-to-landline conversion. On the other hand, the PRU receives baseband signals of the proper protocol from the PMU and modulates them to the appropriate radio frequency.

As illustrated in FIGS. 12 and 13, the PMU 105 includes six functional subsystems: a Pico-BTS main controller card 125 (PMCC), a Pico-BTS channel card 130 (PCC), a transmit and receive interface card 135 (TRIC), a time and frequency card 140 (TFC), and a power supply assembly 145 (PSA) for converting AC to DC and for distributing the DC power throughout the PMU 105 and the PRU 110. The temperature management subsystem 150 is not shown in FIGS. 12 and 13 to simplify the Figures.

In operation, the PMCC 125, which includes an external interface module and a communications controller module, often called a packet engine, monitors all of the cards in the BTS architecture 100 and routes traffic and signaling packets between a Base Station Controller (BSC, see FIG. 3) shown) and the PCCs 130. Likewise, the TRIC 135 provides the interfaces between the transceiver module 155 and the PCCs 130. The PCCs 130 are responsible for converting landline communication information into the proper protocol baseband (such as CDMA) for transmission to a PRU 110 via a cable 122. The TRIC 135 provides the connectivity to the PRU 110 through interconnect cables 122.

Baseband analog signals and intermediate frequency (IF) signals of frequency range lower than that of the over-the-air radio frequency (RF) (eg. of about 1 KHz to about 700 MHZ) are propagated in cables 122 connecting PMU 105 with PRU 110. One preferred IF frequency for the receive link is 239 MHZ with a 1.26 MHZ bandwidth and with an analog base band for the transmit link. The advantage of this approach is that the transmit and receive signals can be duplexed and sent through a standard, inexpensive RG-58 coaxial cable. Other signals to be carried between the units include 48V power, a 10 MHZ reference, and RS-422 control lines.

The separation of the PRU 110 and the PMU 105 allows the PRU 110 to be installed close to the antennas 120. Since in practice power losses in the antenna cable degrade receiver sensitivity and reduce the transmit power at a 1:1 ratio (dB per dB), locating the PRU 110 in close proximity to the antenna 120 maximizes the performance of the BTS 100. The location of the PRU also reduces power and signal losses through a cable and thereby may save energy and increase efficiency.

It is worth noting that all wires and coaxial cables may be bundled into a single polymer jacket. Thus, a single multi-wire/coaxial connector is used at both ends of the cable. The resulting cable is typically built as a unitary item which provides ease of installation and repair in the field. Thus, the cable diameter may easily be kept under 0.75 inches, providing easy installation in the field, as well as in an indoor application (which require turning corners).

Coaxial cables coming into PRU 110 are transformer coupled to the transceiver, which eliminates the possibility of ground loops (and their corresponding ground noise), and ensures that the PRU 110 can be placed up to and in excess of 150 feet away from PMU 105. In addition, if the PRU 110 is connected to a pole or other conductive structure which is grounded, there will be no system performance degradation due to noise coupling. Power, at 24 or 48 VDC or an AC voltage, is sent to the tower top with a separate return. This provides less power loss in the power wires, making the system more efficient.

The signals carried by the cable 122 between PMU 105 and PRU 110 operate most efficiently over a range of about 1 KHz to 240 MHZ. This results in low signal attenuation, even when using thin, low cost cables.

In certain environments wherein heavy communication traffic is prevalent, it may be advantageous to connect two PRUs together and use two carrier frequencies. The exemplary embodiment can connect two PRUs together and transmit and receive two carrier frequencies with minimal degradation of signal quality and without increasing the number of antennas required. This is advantageous because the public is not subjected to additional potentially unsightly antenna yet acquires additional service from the PRU via an effective doubling of communication traffic capabilities.

In order to simplify the disclosure, duplex and diversity channels for a single PRU are described for a single carrier frequency configuration in FIG. 14. It is understood that a PRU can be controlled to operate at different carrier frequencies, but a single carrier frequency at a time. In single carrier mode the service provider need only install one PRU for each sector. PRU-A 110 has two antennas: a duplex antenna (DX) 200 and a diversity antenna (RX) 210. The DX antenna 200 is shared by transmitter circuitry 212 and duplex receiver circuitry 214. The transmitter 212 transmits at an operating frequency T1. Both receivers DX and RX will down convert a received signal to received frequency R1. Preferably T1 and R1 frequencies have a frequency separation, which is dependant on the frequency band of form a frequency pair. The sector 2 and sector 3 PRUs are substantially the same as PRU-A 110. Note that the transmitter circuitry 212 and the duplex receiver circuitry 214 share the DX 200 antenna.

The diversity antenna 210 is in no way connected to the transmitter circuitry 212. Received signals come in the diversity antenna 210 and are provided to the diversity receiver 216. The duplex and diversity received signals are combined in the PMU 218 to improve the carrier to noise ratio (and/or Eb/No). This combining of signals helps negate the effects of fading and multipath found in the received signals.

The combination of PRU-A 110, PRU-B, and PRU-C cover three sectors or 360° about a cell tower. It is understood that a single PRU 110 could be used in an omni-directional mode such that there would be two omni antennas, one for DX 200 and one for RX 210. FIG. 14 discloses an exemplary embodiment of the present invention that provides a PRU 110 for transmitting and receiving a communication signal and further have a diversity receiver which reduces degradation effects of fading and multi-path signals.

FIG. 15 depicts another exemplary embodiment of the present invention. Here an exemplary dual carrier frequency 3-sector configuration for a CDMA transmitter/receiver is shown wherein only two antennas are required and diversity reception is still maintained. It is understood that various protocols, or power levels can be supported as discussed above. The additional requirement for a dual carrier mode for each sector over a single carrier mode in each sector requires an additional PRU per sector and an additional PMU for the site location. No additional antennas are required.

The DX antenna 200 is shared by both transmitter circuitry 212A, the duplex receiver 214A in PRU-A 110A and the diversity receiver 216B in PRU-B 110B. The RX antenna 210 is shared by the transmitter 212B, the duplex receiver 214B found in PRU-B 110B and the diversity receiver 216A in PRU-A 110A.

Each signal after entering the duplex receiver (214A, 214B) is split by a power splitter (see FIG. 16) such that substantially half the signal is provided to the diversity receiver in the other PRU. More specifically, the signal to duplex receiver A 214A is split by a 3 dB power splitter. One

output of the splitter is provided to the duplex receiver A **214A** and the second output of the splitter is provided to diversity receiver B **216B** found in PRU B **110B**. The duplex receiver signal in PRU B **110B** is split in the same fashion as that just described in PRU A **110A**. PRU A **110A** will operate at frequency pair #1 and PRU B will operate at frequency pair #2. The signal from the DX antenna **200** which is split and provided to duplex receiver A **214A** is processed by the duplex receiver A **214A** and becomes the duplex signal for frequency pair #1 (DXA1). The signal from the RX antenna which is provided to PRU B **110B** is split in the duplex receiver B **214B** and provided to the diversity receiver A **216A** of PRU A **110A**. Thus, the signals processed in duplex receiver A **214A** and diversity receiver A **216A** are substantially the same as those found in the single carrier mode, where the DX antenna **200** provides signal to the duplex receiver A **214A** and the RX antenna **210** provides a signal to the diversity receiver **216A**. Thus, the outputs DXA1 and RXA1 and the signal being transmitted by transmitter A **212A** are all associated with the same frequency pair #1. RXA1 is the diversity signal associated with DXA1.

With respect to PRU B **110B**, it utilizes the RX antenna **210** for transmitting the transmit signal for frequency pair #2 via transmitter B **212B**. Furthermore, a signal received from the RX antenna is split such that 3dB of the signal is provided to the duplex receiver B **214B** and 3dB of the signal is provided to diversity receiver A **216A**. Thus, separate antennas are being utilized for the received duplex and diversity receivers. Furthermore, the second frequency pair is being transmitted and received by PRU B **110B**. Output signals RXB2 and DXB2 can be provided to PMU B via the associated cable as the diversity and duplex signals.

Receive diversity is maintained as both PRUs (A&B) provide independent receive signals back to their respective PMUs. The advantage with this exemplary configuration in that capacity is doubled as there are now two frequencies being utilized. Most importantly, the doubling of capacity is accomplished without installing additional antennas. Further, no hardware reconfiguration is required inside the PRUs. An additional advantage is the savings in non-recurring engineering costs and set-up costs due to the expansion ability provided by this exemplary embodiment. Minor exterior cabling modifications may be required to the PRUs to achieve the dual carrier configuration. Note that sectors **2** and **3** can be configured in a similar fashion as sector **1** in this embodiment.

FIG. **16** is a high level schematic representation of the duplex and diversity receiver channels. One can discern from FIG. **16** that these receivers can be configured for either a single or dual carrier frequency configuration. It is understood that FIG. **16** does not include all the circuitry required, but instead is a schematic block diagram that discloses the fundamentals of an exemplary embodiment of the present invention understandable by one of ordinary skill in the art.

FIG. **16** is divided into a duplex receiver portion and a diversity receiver portion which are found within an exemplary PRU **110**. Looking at the duplex portion of the drawing, the duplex antenna **200** receives a signal and provides it to a receiver gain stage **300**. The signal is then provided to an RF splitter **302**. The RF splitter is preferably a 3dB power splitter. A portion of the signal proceeds to attenuator 1 **304** and then to another receiver gain stage **306**. The signal output from the receiver gain stage **306** is then downconverted and provided as the received duplex signal (RxIF_DUP).

If the PRU is set up for a dual carrier wherein two PRU are in use, a portion of the signal is output from the RF splitter **302** to an attenuator **308**, the output of which would be provided as an input to the other PRU.

Referring to the diversity portion of exemplary PRU in FIG. **16**, when the PRU is configured for single carrier frequency processing, an RF signal is received by the diversity antenna and provided to a receive gain stages section **310**. The signal is then provided to an attenuator **311** and then to a single pole double throw (SPDT) switch **312**. The SPDT switch **312** is controlled by amplifier bias and switch control circuitry **314** which in turn is controlled by the associated PMU.

When the SPDT switch **314** is in position "1" the signal is sent, in essence, from the diversity antenna **210** through the SPDT switch **312** and to another gain stage portion **316**. The signal is then sent, via a mixer **318**, to IF circuitry in the diversity receiver portion in the PRU and then finally to the PMU.

Conversely, if the exemplary PRU is in a dual carrier frequency mode, the diversity antenna **210**, gain stage **310**, and attenuator **311** are not used. Instead the diversity signal is received from the other PRU unit. (See FIG. **15**) The signal is received at the SPDT switch **312** on pole **2** and then provided to the gain stage **316**, the mixer **318** and finally provided to the appropriate PMU (as RXIF_DIV).

FIGS. **17**(*a–e*) depict a plurality of exemplary embodiment configurations for the present invention. FIG. **17**(*a*) is an omni mode, single frequency configuration setup with a diversity antenna. The PRU has two antennas one for duplex and one for diversity. The PRU is connected to the PMU. The PMU may have a global positioning system (GPS) antenna connected to it.

FIG. **17**(*b*) depicts an omni setup or single sector setup with two PRUs such that the system is operating with two carrier frequencies with two antennas one for diversity and the other for duplex. The PMU here can be either two PMUs or one PMU that handles two frequencies.

FIG. **17**(*c*) depicts an omni, three carrier system with diversity that requires only four antennas. FIG. **17**(d) depicts a three-sector, single frequency system with no antenna sharing. This system maintains both duplex and diversity reception for each sector.

FIG. **17**(*e*) depicts an omni, six-carrier frequency system with antenna sharing. Thus, six carrier frequencies are handled with diversity reception with six receive/transmit antennas.

Thus, the exemplary embodiments disclose a PRU device that can be connected to handle one or two carrier frequencies without increasing antenna requirements. The present invention allows a service provider to upgrade a cellular (PCS) communication system from a single to a dual carrier frequency by only requiring the addition of a PRU and a cabling change. No new antenna(s) needs to be installed on a tower. No changes in technology or re-engineering cost are required. The result is twice the cellular (PCS) communication capacity without the addition of unsightly antennas. Basically a service provider buys another PRU, hangs the PRU on the existing antenna tower, then recables the external cabling to achieve double the communication capacity. This is a major advancement in cellular (PCS) technology and upgradability.

While the invention has been particularly shown and described with reference to specific embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made thereto, and that

other embodiments of the present invention, beyond embodiments specifically described herein, may be made or practiced without departing from the spirit and scope of the present invention as limited solely by the appended claims.

What is claimed is:

1. A base station transceiver system comprising:

a first radio unit adapted for mounting proximate a top of a utility pole associated with said base transceiver system, said first radio unit comprising:

a first variable power amplifier capable of transmitting amplified transmit signals to a first antenna disposed proximate said top of said utility pole;

a first transceiver circuitry coupled to said first variable power amplifier; and

a first controller circuit electrically coupled to said first transceiver circuitry and to said first variable power amplifier; and

a main unit capable of being distally positioned from said first radio unit and capable of coupling said base station transceiver to a landline telecommunication system and providing base band telecommunication signals to said first radio unit, said main unit comprising a controller circuit for receiving control signals from said landline and providing said control signals to said first radio unit to set the first variable power amplifier to an output power setting.

2. The base station transceiver system of claim 1, wherein said main unit provides said control signals to said first controller circuit of said first radio unit.

3. The base station transceiver system of claim 1, wherein said first radio unit is adapted to be directly couplable to said first antenna.

4. The base station transceiver system of claim 1, further comprising:

a second radio unit adapted for mounting proximate said top of said utility pole, said second radio unit comprising:

a second variable power amplifier capable of transmitting amplified transmit signals to a second antenna disposed proximate said top of said utility pole;

a second transceiver circuitry coupled to said second variable power amplifier; and

a second controller circuit electrically coupled to said second transceiver circuitry and to said second variable power amplifier;

wherein said main unit is capable of providing base band telecommunication signals to said second radio unit and providing control signals to said second radio unit in order to control said second variable power amplifier's output power.

5. The base station transceiver of claim 4, wherein said first radio unit is adapted to be directly coupled to a second antenna, said first radio unit and said second radio unit are coupled to each other such that said first antenna and said second antenna are shared by said first radio unit and said second radio unit.

6. The base station transceiver of claim 5, wherein said first radio unit transmits a first frequency via said first antenna and said second radio unit transmits a second frequency via said second antenna.

7. The base station transceiver of claim 5, wherein said first radio unit is capable of receiving a first duplex signal from said first antenna and a first diversity signal from said second antenna and wherein said second radio unit is capable of receiving a second diversity signal from said first antenna and a second duplex signal from said second antenna.

8. The base station transceiver of claim 4, wherein said main unit further comprises a first channel circuit which receives a first telecommunication signal from a landline, said first channel circuit converts said first telecommunication signal to a first baseband wireless telecommunication protocol and provides said first baseband wireless telecommunication protocol to said first radio unit.

9. The base station transceiver of claim 8, wherein said main unit further comprises a second channel circuit which receives a second telecommunication signal from said landline, said second channel circuit converts said second telecommunication signal to a second baseband wireless telecommunication protocol and provides said second baseband wireless telecommunication protocol to said second radio unit.

10. The base station transceiver of claim 9, wherein said first baseband wireless telecommunication protocol is a CDMA protocol.

11. The base station transceiver of claim 9, wherein said first baseband wireless telecommunication protocol is at least one of a digital and an analog wireless telecommunication protocol.

12. The base station transceiver of claim 9, wherein said first baseband wireless telecommunication protocol and said second baseband wireless telecommunication protocol are different protocols.

13. A base station transceiver system for a wireless telecommunication system, said base station transceiver system comprising:

a main unit capable of being coupled to a public switched telephone network (PSTN), wherein said main unit receives a plurality of telecommunication signals from said PSTN, said main unit comprising:

a first channel circuit for converting a first telecommunication signal from said PSTN to a first wireless telecommunication protocol signal; and

a second channel circuit for converting a second telecommunication signal from said PSTN to a second wireless communication protocol signal;

a first radio unit adapted for mounting proximate a top of a utility pole associated with said base transceiver system, said first radio unit distally located from and in communication with said main unit, said first radio unit comprising:

a first controller circuit;

a first transceiver circuit connected to said first controller circuit; and

a first power amplifier connected to said first transceiver, to said first controller circuit, and capable of being coupled to a first antenna disposed proximate said top of said utility pole, said first radio unit receives said first wireless telecommunication protocol signal from said main unit and modulates said first wireless telecommunication protocol signal with a first predetermined frequency and transmits said first wireless telecommunication protocol via said first antenna; and

a second radio unit distally located from and in communication with said main unit, said first radio unit comprising:

a second controller circuit;

a second transceiver circuit connected to said second controller circuit; and

a second power amplifier connected to said second transceiver, to said second controller circuit and capable of being coupled to a second antenna disposed proximate said top of said utility pole, said

second radio unit receives said second wireless telecommunication protocol signal from said main unit and modulates said second wireless telecommunication protocol signal with a second predetermined frequency and transmits said second wireless telecommunication protocol via said second antenna.

14. The base station transceiver system for a wireless telecommunication system of claim 13, wherein said first wireless telecommunication protocol and said second wireless telecommunication protocol are different protocols.

15. The base station transceiver system for a wireless telecommunication system of claim 13, wherein each of said first wireless telecommunication protocol and said second wireless telecommunication protocol are selected from the group consisting of CDMA, TDMA, GSM AMPS, and NAMPS.

16. The base station transceiver system for a wireless telecommunication system of claim 13, where said first predetermined frequency and said second predetermined frequency are the same.

17. The base station transceiver system for a wireless telecommunication system of claim 13, wherein said first power amplifier is a variable power amplifier that can be controlled by said first controller circuit.

* * * * *

US005963583A

United States Patent [19]

Davidovici et al.

[11] **Patent Number: 5,963,583**

[45] **Date of Patent: Oct. 5, 1999**

[54] **FUZZY-LOGIC SPREAD-SPECTRUM ADAPTIVE POWER CONTROL**

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[21] Appl. No.: **09/007,026**

[22] Filed: **Jan. 14, 1998**

Related U.S. Application Data

[63] Continuation of application No. 08/536,749, Sep. 29, 1995, Pat. No. 5,719,898.

[51] **Int. Cl.**[6] **H04B 15/00**; H04K 1/00; H04L 27/30

[52] **U.S. Cl.** **375/200**; 375/207; 455/38.3; 455/522; 706/1

[58] **Field of Search** 375/200, 205, 375/207, 208, 219, 221, 227, 343, 344, 346; 370/319, 311, 332, 335; 455/38.3, 522, 68–70, 88; 364/148.05; 706/1

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Assistant Examiner—Bryan Webster
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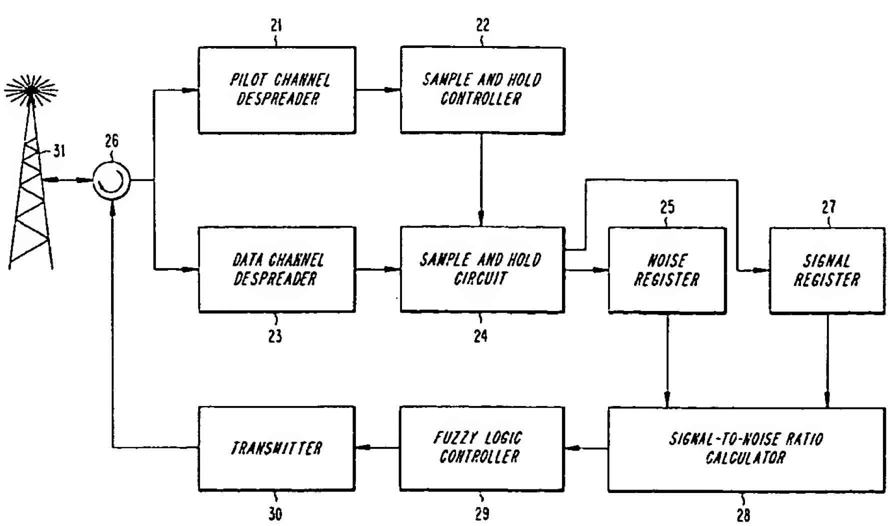
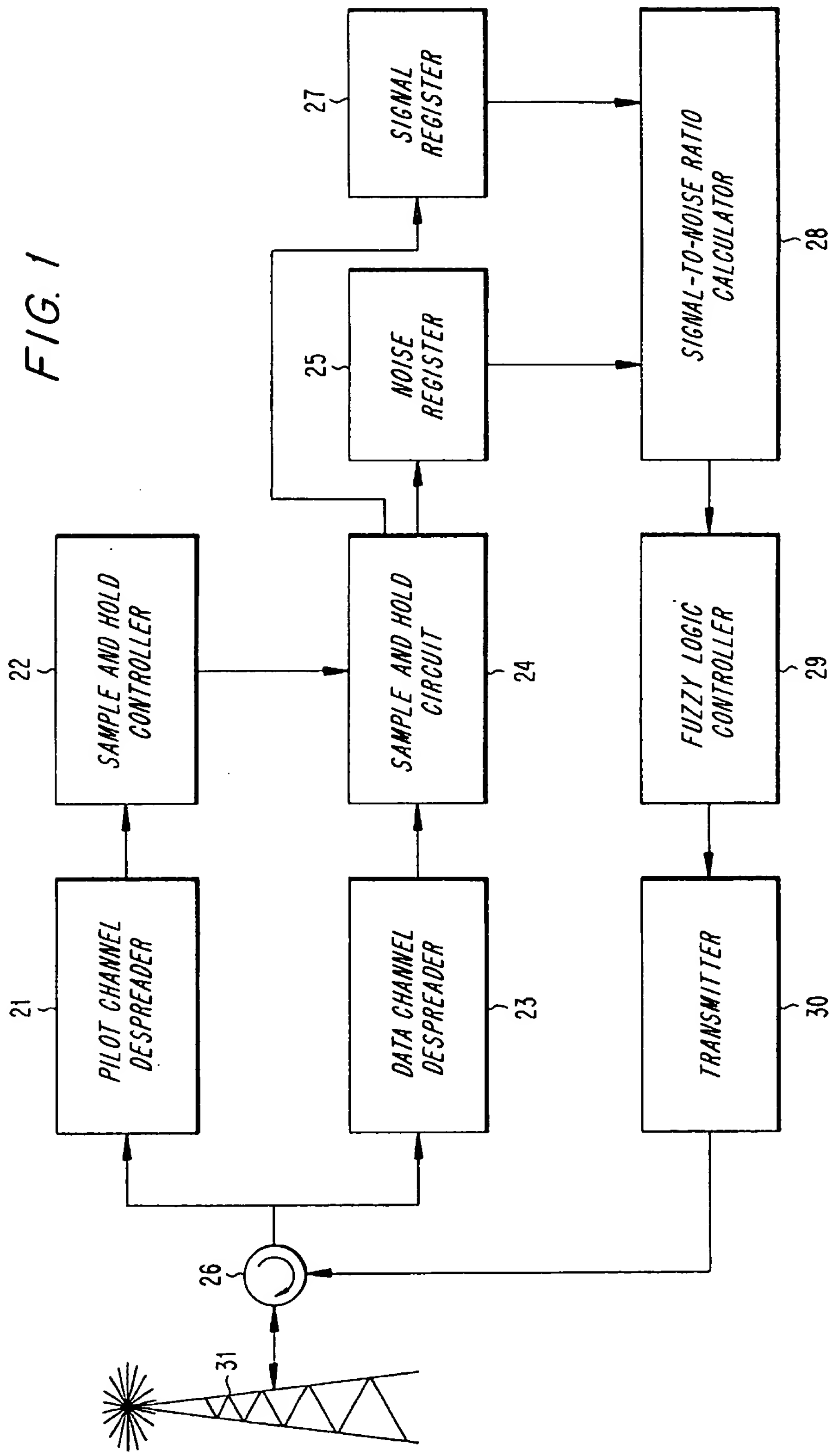
[57] **ABSTRACT**

A fuzzy-logic spread-spectrum adaptive power control system comprising a base station and a plurality of remote units. The base station receives a spread-spectrum signal, and samples the despread spread-spectrum signal at a peak correlation time of the data channel, and at a non-peak correlation time of the data channel. This in turn generates a signal level and a noise level, respectively. A signal-to-noise ratio calculator generates a signal-to-noise ratio from the signal level and the noise level. A fuzzy-logic controller compares the signal-to-noise ratio to a set of predetermined thresholds, and using a state machine, generates a control signal which is thereby transmitted to the remote unit, indicating the amount by which to increase or decrease transmitted power. Each remote unit demodulates the control signal, and a transmitter controller adjusts a power level of the remote-unit spread-spectrum transmitter.

7 Claims, 7 Drawing Sheets

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27
SIGNAL-TO-NOISE RATIO CALCULATOR
28
NOISE REGISTER
25
SAMPLE AND HOLD CONTROLLER
22
SAMPLE AND HOLD CIRCUIT
24
FUZZY LOGIC CONTROLLER
29
PILOT CHANNEL DESPREADER
21
DATA CHANNEL DESPREADER
23
TRANSMITTER
30
26
31

FIG. 1

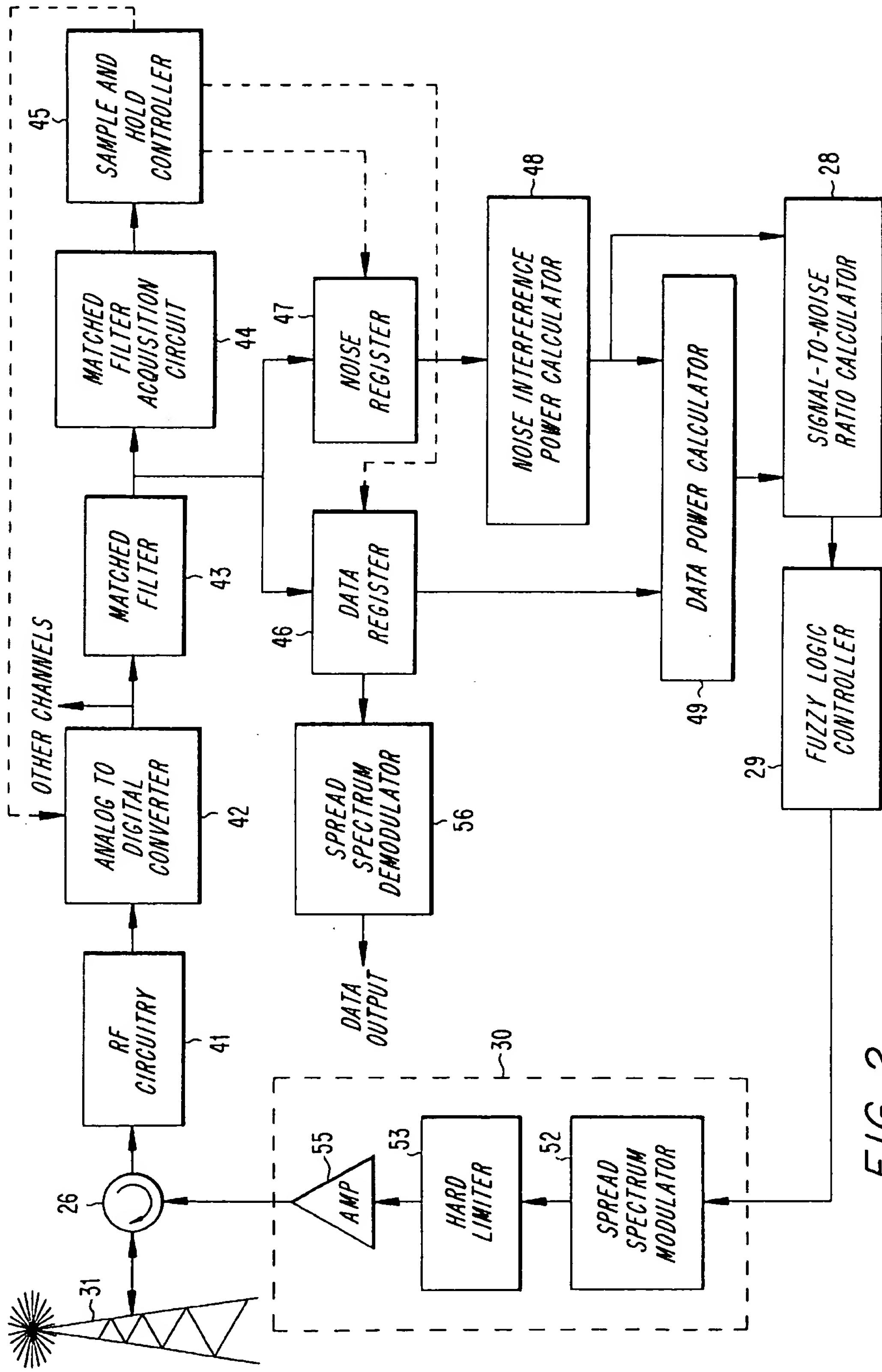

SAMPLE AND HOLD CONTROLLER
45
MATCHED FILTER ACQUISITION CIRCUIT
44
MATCHED FILTER
43
OTHER CHANNELS
ANALOG TO DIGITAL CONVERTER
42
RF CIRCUITRY
41
26
31
NOISE REGISTER
47
DATA REGISTER
46
SPREAD SPECTRUM DEMODULATOR
56
DATA OUTPUT
NOISE INTERFERENCE POWER CALCULATOR
48
DATA POWER CALCULATOR
49
SIGNAL-TO-NOISE RATIO CALCULATOR
28
FUZZY LOGIC CONTROLLER
29
30
AMP
55
HARD LIMITER
53
SPREAD SPECTRUM MODULATOR
52

FIG. 2

FIG. 3

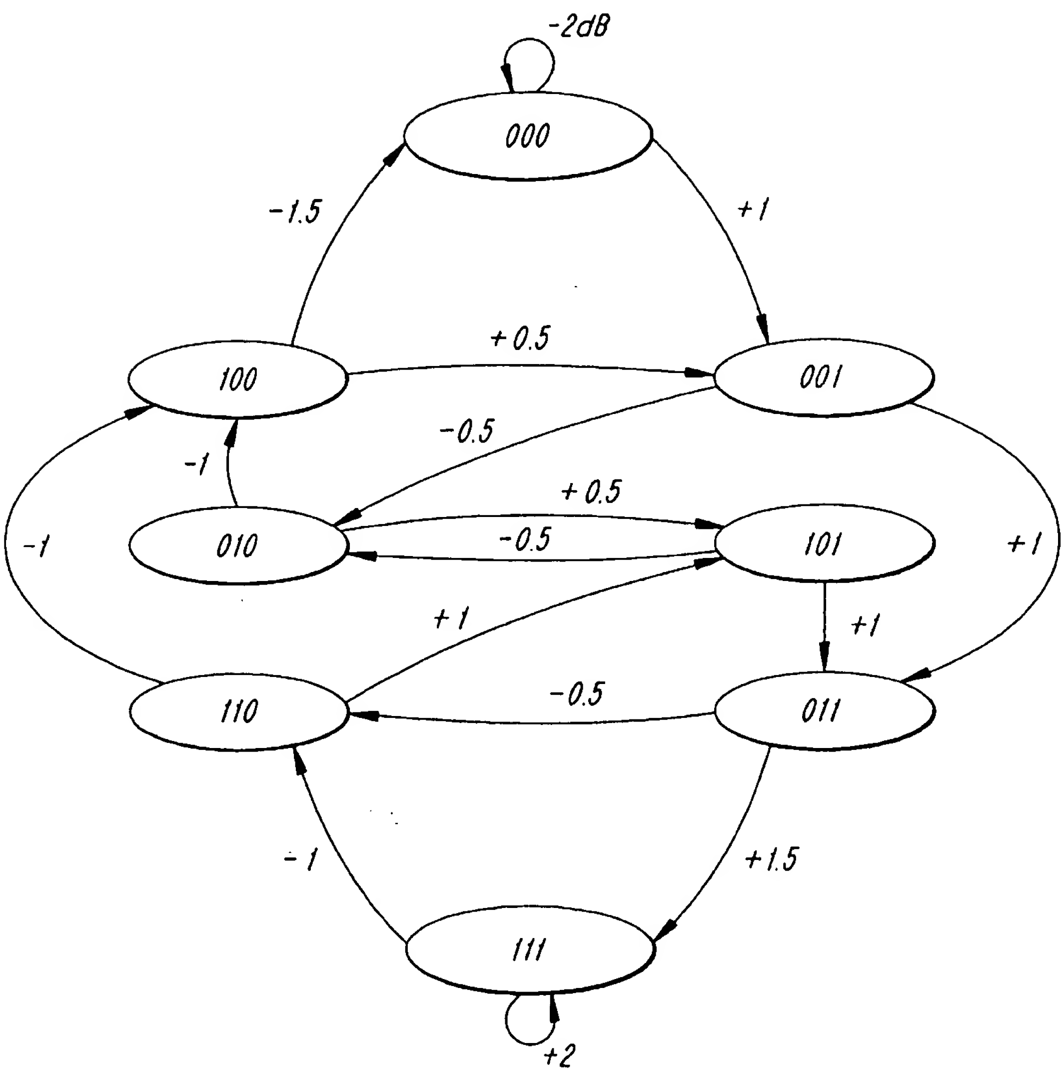
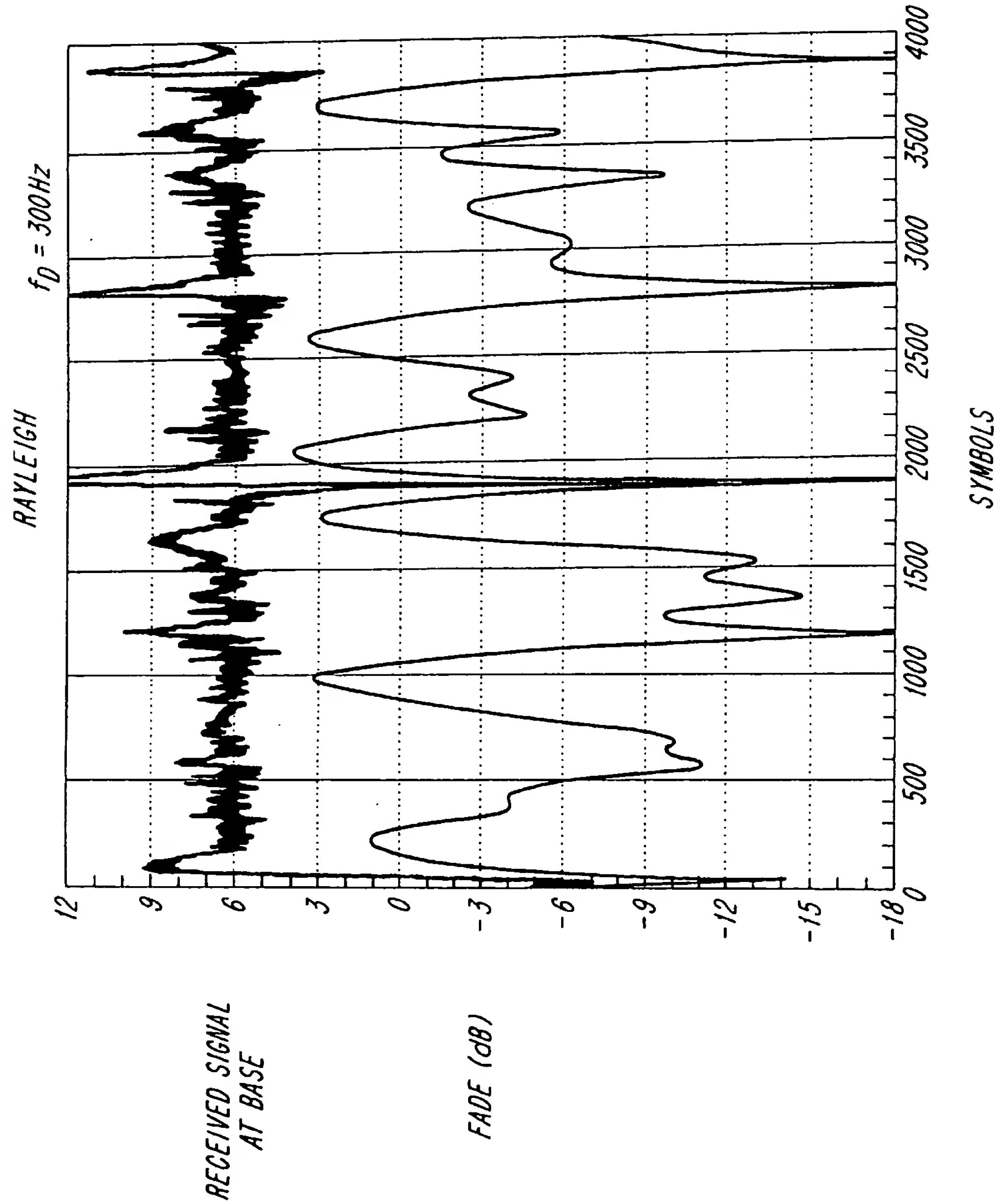


FIG. 4



RAYLEIGH
f_D = 300Hz
RECEIVED SIGNAL AT BASE
FADE (dB)
12
9
6
3
0
-3
-6
-9
-12
-15
-18
0
500
1000
1500
2000
2500
3000
3500
4000
SYMBOLS

FIG. 5

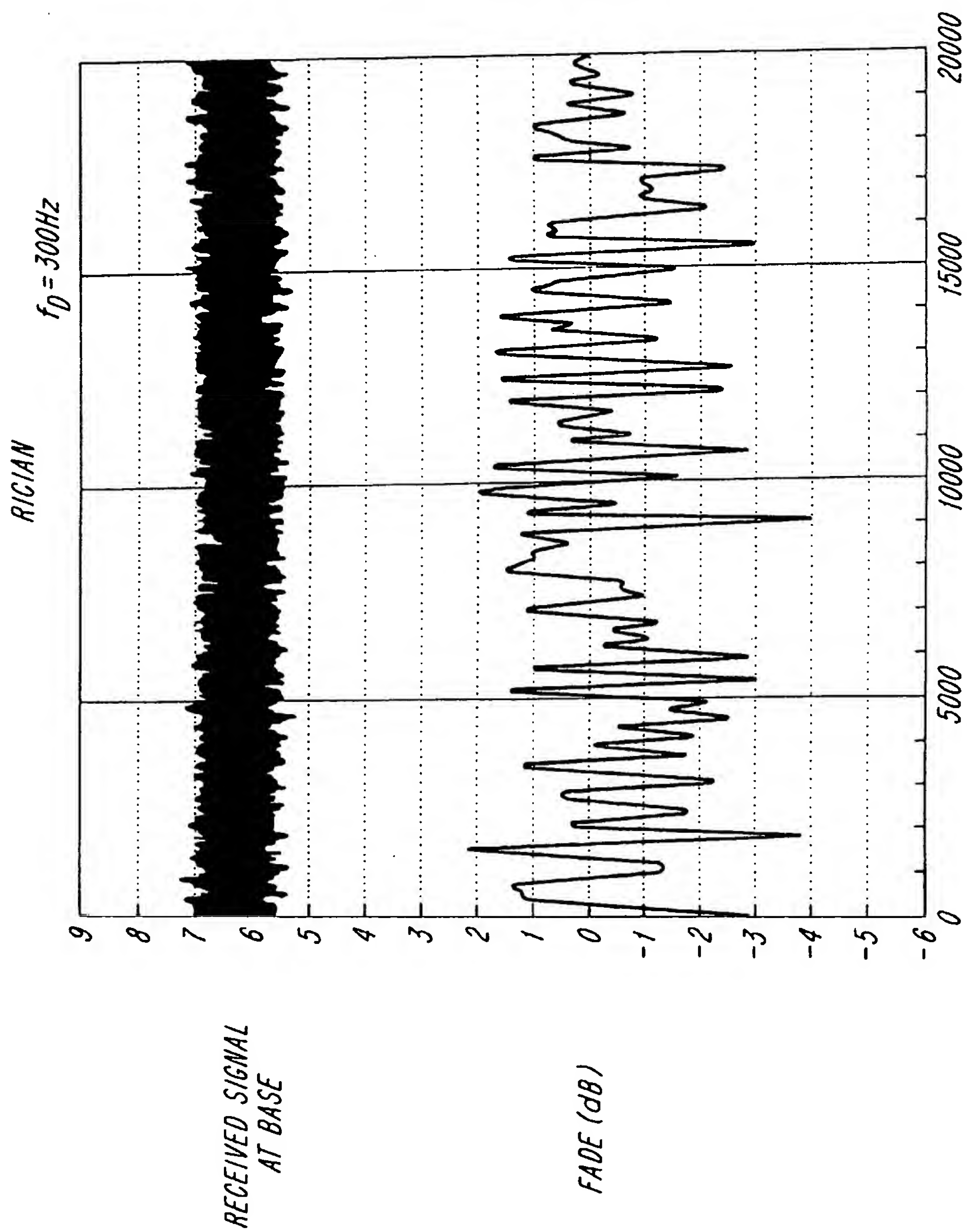

RICIAN
$f_D = 300Hz$
RECEIVED SIGNAL AT BASE
FADE (dB)
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
5000
10000
15000
20000

FIG. 6

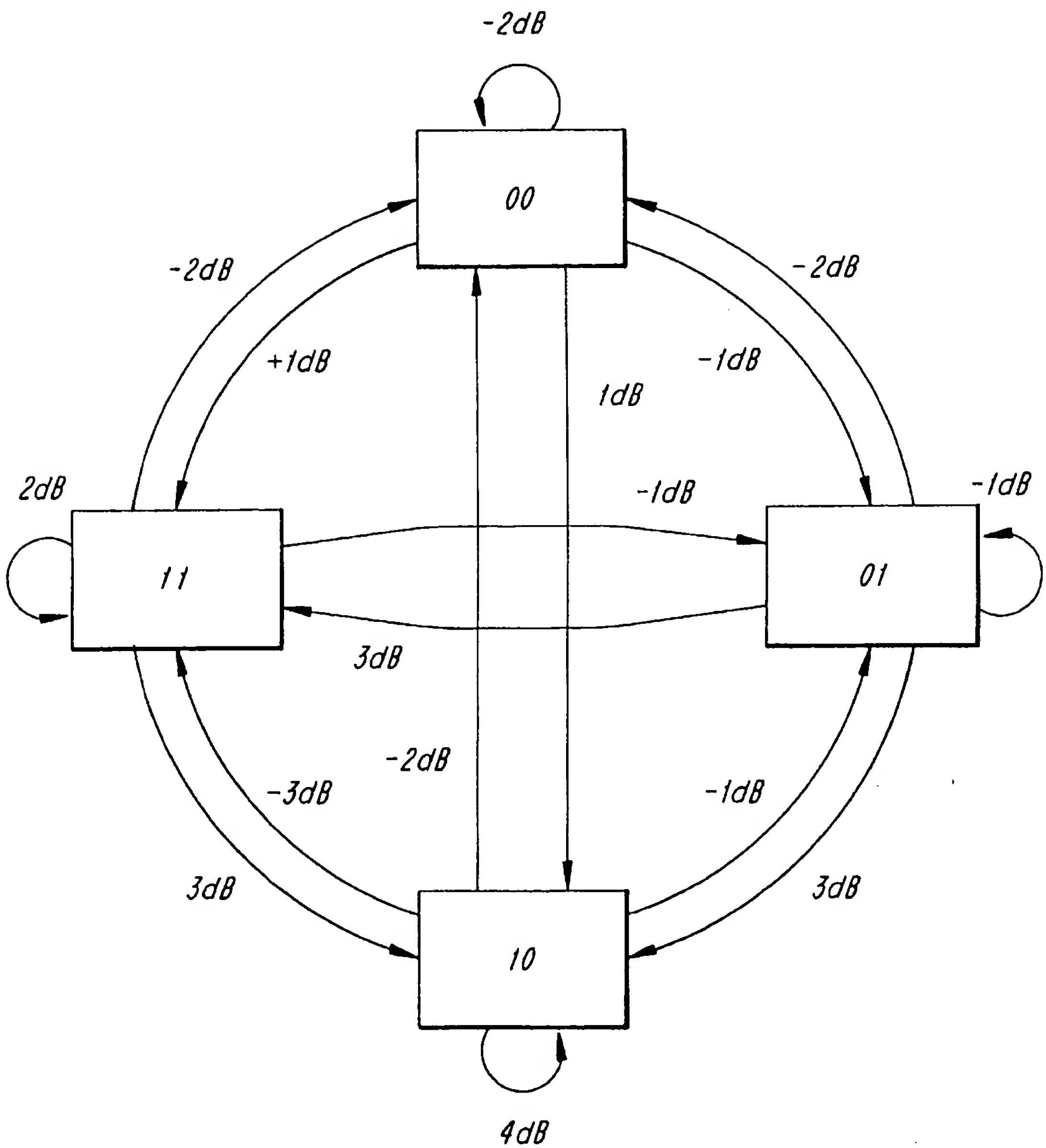
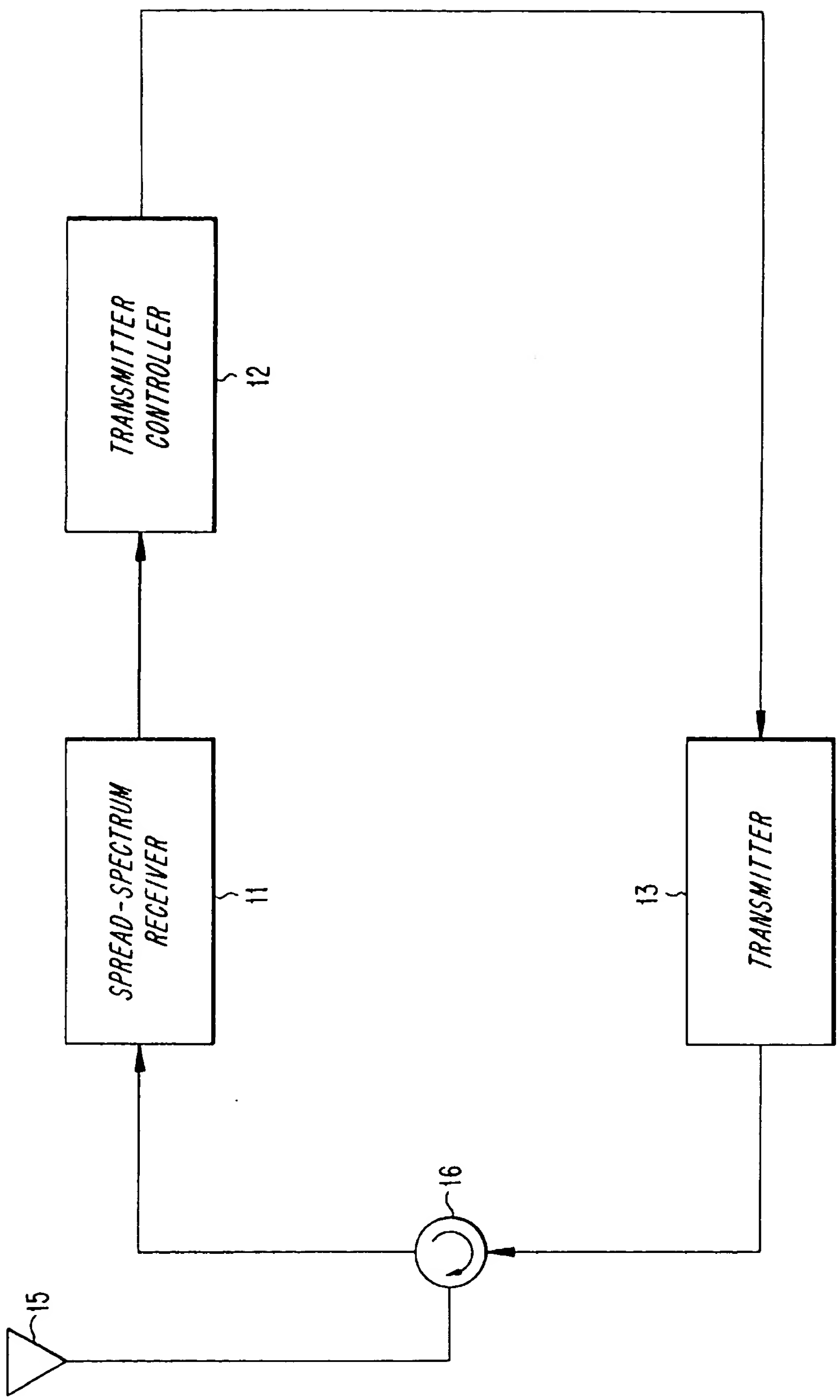

-2dB
00
-2dB
-2dB
+1dB
-1dB
1dB
2dB
-1dB
-1dB
11
01
3dB
-2dB
-3dB
-1dB
3dB
3dB
10
4dB

FIG. 7


TRANSMITTER CONTROLLER
12
SPREAD-SPECTRUM RECEIVER
11
TRANSMITTER
13
16
15

FUZZY-LOGIC SPREAD-SPECTRUM ADAPTIVE POWER CONTROL

This patent stems from a continuation application of a patent application entitled, FUZZY-LOGIC SPREAD-SPECTRUM ADAPTIVE POWER CONTROL, having Ser. No. 08/536,749, and filing date Sep. 29, 1995, now U.S. Pat. No. 5,719,898. The benefit of the earlier filing date of the parent patent application is claimed pursuant to 35 U.S.C. § 120.

BACKGROUND OF THE INVENTION

This invention relates to spread-spectrum communications, and more particularly to an adaptive power controller using a state machine, for controlling a power level transmitted by a remote unit.

DESCRIPTION OF THE RELEVANT ART

The need for a means of controlling the power from remote users, simultaneously transmitting to and being received at a common base station, is well known and documented in the literature. As an example, consider the paper by Ormondroyd entitled, POWER CONTROL FOR SPREAD-SPECTRUM SYSTEMS published in April 1982 from the Conference on Communications Equipment and Systems in the United Kingdom and associated with the IEEE Communications Society (USA). In suggesting a particular power control solution, Ormondroyd references five additional papers dating back to 1979 which also describe the need for and means of effecting power control.

In recent times, several patents have been issued to inventors who have demonstrated their ingenuity by preparing algorithms which they employ to implement the power control required. These patents include:

U.S. Pat. No. 5,093,840, entitled ADAPTIVE POWER CONTROL FOR A SPREAD SPECTRUM TRANSMITTER and incorporated herein by reference, issued to Schilling on Mar. 3, 1992 and describes an apparatus for adaptive-power control (APC) of a spread-spectrum transmitter of a mobile station operating in a cellular-communications network using spread-spectrum modulation. A base station transmits a generic (pilot) spread-spectrum signal and an APC-data signal. The APC-data signal includes a threshold to be used by the mobile station. The mobile station has an acquisition circuit for acquiring and decoding the pilot spread-spectrum signal, a detector for detecting a received power level of the pilot spread-spectrum signal, a decoder for decoding the APC-data signal as a threshold, a differential amplifier for generating a comparison signal by comparing the received power level to the threshold, a transmitter for transmitting a transmitter spread-spectrum signal, and a variable-gain device which, in response to the comparison signal indicating an increase or decrease, adjusts a transmitter-power level of the transmitter spread-spectrum signal. Key to this patent is the APC-data signal which provides a threshold for comparing a received power level, and determining whether to increase or decrease the transmitted power level.

U.S. Pat. No. 5,257,283, entitled SPREAD SPECTRUM TRANSMITTER POWER CONTROL METHOD AND SYSTEM and incorporated herein by reference, issued to Gilhousen et al., on Oct. 26, 1993 and discloses a power control system for a cellular mobile telephone system in which system users communicate information signals between one another via at least one cell site using code division multiple access spread-spectrum communications signals. Cell-site transmit signal power is measured as received at the mobile unit. Transmitter power is adjusted at the mobile unit in an opposite manner with respect to increases and decreases in received-signal power. A power control feedback scheme also may be used. At the cell-site communicating with the mobile unit, the mobile unit transmitted power is measured as received at the cell-site. A command signal is generated at the cell-site and transmitted to the mobile unit for further adjustment of mobile unit transmitter power corresponding to deviations in the cell-site received signal power.

U.S. Pat. No. 5,299,226, entitled ADAPTIVE POWER CONTROL FOR A SPREAD SPECTRUM COMMUNICATIONS SYSTEM AND METHOD and incorporated herein by reference, issued to Schilling on Mar. 29, 1994, and discloses an adaptive power control method and apparatus for spread-spectrum communications, for use with a mobile station operating in a cellular communications network. A base station transmits a first spread-spectrum signal. A mobile station has an automatic-gain-control (AGC) circuit for generating an AGC-output signal from a received signal. The received signal includes the first spread-spectrum signal and an interfering signal. The mobile station also has a correlator for despreading the AGC-output signal, and a power-measurement circuit which operates in response to processing the received signal with the despread AGC-output signal, for generating a received-power level. The mobile station also has a comparator coupled to the power-measurement circuit for generating a comparison signal by comparing the received-power level to a threshold level, and a transmitter for transmitting a second spread-spectrum signal. A variable-gain device, in response to the comparison signal, adjusts the transmitter-power level of the second spread-spectrum signal.

U.S. Pat. No. 5,386,588, entitled TRANSMISSION POWER CONTROL OF MOBILE RADIOTELEPHONE STATION IN RESPONSE TO BASE STATION CONTROL SIGNAL WHERE BASE STATION DATA IS COLLECTED BY THE MOBILE RADIOTELEPHONE STATION and incorporated herein by reference, issued to Yasuda on Jan. 31, 1995, and discloses transmission power control of a mobile radiotelephone station in which radio communication channels, including control channels and a plurality of communication channels, are set between a plurality of base stations and a plurality of mobile stations within radio zones of the base stations. An outgoing call and an incoming call are controlled and the communication channels are designated via the control channels. A telephone conversation is made via the communication channels, and channels of different frequencies are allocated to different radio zones. Each base station includes a circuit for detecting the received electric field intensity of the mobile station after being passed through the channel. The base station receiver is set such that when the mobile station is moved between the radio zones, the mobile station is consistently connected to the base station whose communication state is satisfactory.

In the foregoing patent disclosures, control signals are sent for determining thresholds based on the signal intensity or power of a received spread-spectrum signal. The prior art does not teach measuring the signal power level of a received spread spectrum signal along with-the noise level within the same frequency band and within approximately the same time, for determining a signal-to-noise ratio (SNR). More particularly, these prior art patents compare a received level to a predetermined threshold and increase or decrease power accordingly. They do not teach measuring signal-to-

noise ratio at the despreader, while attempting to bound the variation of the signal-to-noise ratio using a state diagram.

Further, the prior art patents do not teach the use of a state diagram for a fuzzy-logic solution to the problem of determining or adjusting the power level in response to the requirements of the environment. For example, in a typical mobile environment, a remote unit might pass through a geographical area, such as between two buildings, and encounter substantial fading. Absent significant adjustment in the power level, such fading could result in signal loss. The foregoing disclosures do not address an adaptive method or a method using artificial intelligence for adjusting the power level of the remote unit to offset the fading process.

SUMMARY OF THE INVENTION

A general object of the invention is an adaptive power control system and method which adapts to dynamically varying fading and shadowing environments.

Another object of the invention is to employ artificial intelligence to control power levels used by remote units.

An additional object of the invention is to base power control on measured levels of signal power, noise and interference power, on the same frequency band and close in proximity of time.

A further object of the invention is an adaptive power control system which works in a dynamically changing city or office environment.

According to the present invention, as embodied and broadly described herein, a fuzzy-logic spread-spectrum adaptive power control system is provided comprising a base station and a plurality of remote units. The base station includes a base antenna, a pilot-channel despreader, a sample-and-hold controller, a data channel despreader, a sample-and-hold circuit, a signal-to-noise ratio calculator, a fuzzy-logic controller, and a base spread-spectrum transmitter. The circuits required can be built analog or digital.

The base antenna receives a first spread-spectrum signal. The first spread-spectrum signal includes at least one data channel, and may include a pilot channel. The pilot-channel despreader despreads a pilot channel signal embedded in the first spread-spectrum signal. The pilot-channel despreader generates a timing signal from the despread pilot channel signal. The pilot channel is optional, and the timing signal alternatively may be obtained from the data channel.

Using the timing signal, the sample-and-hold controller generates a first control signal and a second control signal. The data-channel despreader despreads a data channel signal embedded in the first spread-spectrum signal as a despread signal. The sample-and-hold circuit, in response to the first control signal, samples the despread signal at a peak correlation time of the data channel signal, and generates from the despread signal a signal level. In response to the second control signal, the sample-and-hold circuit samples the despread signal at a non-peak correlation time of the data channel signal to generate from the despread signal a noise level. The noise level measured includes interference caused by other users as well as thermal noise.

The signal-to-noise ratio calculator generates a signal-to-noise ratio from the signal level and the noise level. The fuzzy-logic controller compares the signal-to-noise ratio to a set of predetermined thresholds. If the number of thresholds employed were M−1, then there are M levels which can be represented by an N bit word where 2^N=M. Thus, depending on the signal-to-noise ratio, the fuzzy logic controller selects the appropriate N bit word, which serves as an N-bit control signal. The base spread-spectrum transmitter transmits a second spread-spectrum signal which includes the N-bit control signal outputted from the fuzzy-logic controller. The second spread-spectrum signal is radiated by the base antenna.

Each remote unit includes a remote-unit antenna, a remote-unit spread-spectrum receiver, a remote-unit spread-spectrum transmitter, and a transmitter controller. The remote-unit spread-spectrum receiver receives the second spread-spectrum signal and demodulates from the second spread-spectrum signal the appropriate N-bit word embedded in the second spread-spectrum signal as the N-bit control signal. The output of the remote-unit spread-spectrum receiver is a demodulated-control signal. The demodulated-control signal actuates the transmitter controller to adjust a power level of the remote-unit spread-spectrum transmitter. The remote-unit spread-spectrum transmitter transmits the first spread-spectrum signal, which includes the pilot channel and the data channel.

The present invention also includes a fuzzy-logic spread-spectrum adaptive power method which comprises the steps of receiving at a base station a first spread-spectrum signal which has a pilot channel and a data channel, and despreading a pilot channel signal embedded in the first spread-spectrum signal. The method also includes generating from the despread pilot channel signal a timing signal, and from the despread pilot channel signal, a first control signal and a second control signal. The use of a pilot channel is optional, and the timing signal alternatively may be obtained directly from the data channel.

The method further includes despreading at the base station a data channel signal embedded in the first spread-spectrum signal as a despread signal. Using the first control signal, the despread signal is sampled at a peak correlation time of the data channel signal to generate a signal level. In response to the second control signal, the despread signal is sampled at a non-peak correlation time of the data channel signal to generate a noise level. The method generates a signal-to-noise ratio from the signal level and the noise level, and compares, at the base station, the signal-to-noise ratio to a set of predetermined thresholds. The signal-to-noise ratio is quantized by comparing it to predetermined thresholds, and the method generates an N bit word where 2^N is the number of quantization levels. The method includes transmitting from the base station the N bit word, denoted herein as an N-bit control signal, as part of a second spread-spectrum signal. The appropriate N-bit word is transmitted periodically every T seconds. In the preferred configuration, T_{APC} should be between 250 microseconds and 500 microseconds, although any T_{APC} is possible.

The method includes receiving, at a remote unit, the second spread-spectrum signal, and demodulating from the second spread-spectrum signal, the N-bit word embedded in the second spread-spectrum signal, as a demodulated-control signal. The method thereby adjusts at the remote unit, in response to the demodulated-control signal, a power level of the first spread-spectrum signal which is transmitted from the remote unit.

Additional objects and advantages of the invention are set forth in part in the description which follows, and in part are obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention also may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate preferred embodiments of the invention, and together with the description serve to explain the principles of the invention.

FIG. 1 is a block diagram of a base station with a fuzzy-logic controller;

FIG. 2 is a more detailed, alternative, block diagram of a base station with a fuzzy-logic controller;

FIG. 3 is a first state diagram of the fuzzy-logic controller;

FIG. 4 illustrates a signal fading in a Rayleigh channel;

FIG. 5 illustrates a signal fading in a Rician channel;

FIG. 6 is a second state diagram of the fuzzy-logic controller; and

FIG. 7 is a block diagram of a remote unit with a transmitter controller.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference now is made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals indicate like elements throughout the several views.

The fuzzy-logic spread-spectrum adaptive power control (APC) system provides a new and innovative technique for achieving power control in a code division multiple access (CDMA) or code division multiplex (CDM), spread-spectrum environment. The APC system also can work in a time division duplex (TDD) code division multiple access (CDMA) system. The technique employs sampling a spread-spectrum signal and sampling noise within the same channel, and combining the two samples to generate a signal-to-noise ratio (SNR). The signal-to-noise ratio is used with fuzzy logic for determining by how much to increase or decrease the power transmitted by a remote unit. The APC system can be constructed using either analog or digital circuits, or a combination of both.

More particularly, the present invention includes a base station and a plurality of remote units. Each base station includes base-pilot means, base-controlling means, base-despreading means, base-sample-and-hold means, base-signal-to-noise ratio means, base-fuzzy means, and base-transmitting means. The base-controlling means is coupled to the base-pilot means. Alternatively, the base-controlling means is coupled to the base-despreading means, if the base-pilot means were not used. The base-sample-and-hold means is coupled between the base-controlling means, the base-despreading means, and the base-signal-to-noise ratio (base-SNR) means. The base-fuzzy means is coupled between the base-SNR means, and the base-transmitting means.

The base-pilot means receives a first spread-spectrum signal. The first spread-spectrum signal has a pilot channel and a data channel. The base-pilot means despreads a pilot channel signal embedded in the first spread-spectrum signal and generates from the despread pilot channel signal, a timing signal. Using the timing-signal, the base-controlling means generates a first control signal and a second control signal.

The base-pilot means is optional. As an alternative, a timing signal may be derived from a data channel signal embedded in the first spread-spectrum signal.

The base-despreading means despreads the data channel signal embedded in the first spread-spectrum signal as a despread signal. In response to the first control signal, the base-sample-and-hold means samples the despread signal at a peak correlation time of the data channel signal to generate from the despread signal, a signal level. A peak correlation time is defined herein to be a time when the correlation output of the base-despreading means is at a peak, i.e., the data channel signal embedded in the first spread-spectrum signal achieves a peak correlation with either a matched filter or a decorrelator embedded in the base-despreading means. In response to the second control signal, the base-sample-and-hold means samples the despread signal at a non-peak correlation time of the data channel signal to generate from the despread signal, a noise level. A non-peak correlation time is defined herein to be a time when the data channel signal embedded in the first spread-spectrum signal does not have a correlation with the correlator or the matched filter as used by the base-despreading means.

If the timing signal were to be derived from the data channel signal, then the base-despreading means would include means for extracting or generating the timing signal from the data channel signal.

The "signal power level" is equal to

$$P_S + \frac{P_N + P_I}{P_G}$$

Where:

P_S=Signal Power

P_I=Interferene Power

P_N=Noise Power

P_G=Processing Gain

The "noise power level" is approximately equal to

$$\frac{P_N + P_I}{P_G}$$

therefore "signal power level" minus "noise power level" is approximately equal to the signal power P_S and

$$\frac{P_S}{P_N + P_I} = SNR$$

The base-SNR means generates a signal-to-noise ratio from the signal level and the noise level, from the base-sample-and-hold means. The base-fuzzy means stores the signal-to-noise ratio for later comparisons. Also, the base-fuzzy means compares the signal-to-noise ratio to a set of predetermined thresholds and generates a signal having N bits when the signal-to-noise ratio falls within one of 2^N levels. Alternatively, the base-fuzzy means may average a plurality of stored signal-to-noise ratios, and compare the averaged signal-to-noise ratio to the predetermined levels. Alternatively, the fuzzy-logic controller can use the quantized SNR and the rate of change of SNR to determine how much correction is required. The signal having N-bits is also denoted herein as an N-bit control signal, and is used for signalling, from the base station to a remote unit, by how much to increase or decrease a power level.

The base-transmitting means transmits the appropriate N-bit signal, as outputted from the fuzzy-logic controller, as part of a second spread-spectrum signal.

A remote unit includes remote-receiving means, remote-transmitting means, and remote-controlling means. The remote-controlling means is coupled between the remote-receiving means and the remote-transmitting means.

The remote-receiving means receives the second spread-spectrum signal transmitted from the base station. The remote-receiving means demodulates from the second spread-spectrum signal, the N-bit control signal embedded in the second spread-spectrum signal, as a demodulated-control signal. In response to the demodulated-control signal, the remote-controlling means. adjusts a power level of the remote-transmitting means. The remote-transmitting means transmits the first spread-spectrum signal with the power level as adjusted by the remote-controlling means.

In the exemplary arrangement shown in FIG. 1, the base station is depicted wherein the base-pilot means is embodied as a pilot-channel despreader **21** coupled through an isolator **26** to an antenna **31**. In a TDD CD MA system, the isolator **26** alternatively may be embodied as a switch. The base-despreading means is embodied as a data-channel despreader **23** coupled to the isolator **26** and the sample-and-hold means is shown as a sample-and-hold circuit **24**. The base-controlling means is embodied as a sample-and-hold controller **22** coupled between the pilot-channel despreader **21** and the sample-and-hold circuit **24**. The base-signal-to-noise ratio means is illustrated as a signal-to-noise ratio calculator **28** coupled through noise register **25** and signal register **27** to the sample-and-hold circuit **24**. The base fuzzy means is illustrated as a fuzzy-logic controller **29** coupled to the signal-to-noise ratio calculator **28**. The base-transmitting means is illustrated as a spread-spectrum transmitter **30** coupled between the fuzzy-logic controller **29** and the isolator **26**.

The base antenna **31** receives the first spread-spectrum signal which includes a data channel. The first spread-spectrum signal may optionally include a pilot channel. If the first spread-spectrum signal included a pilot channel, then the pilot-channel despreader **21** despreads a pilot channel signal embedded in the first spread-spectrum signal, and from the despread pilot channel signal, generates a timing signal. If the pilot channel were not used, then the timing signal may be derived from a data channel signal. A matched filter or correlator, by way of example, may be used for acquiring such a timing signal.

In response to the timing signal, the sample-and-hold controller **22** generates a first control signal and a second control signal. The first control signal and the second control signal are generated at different points in time, so that the first control signal occurs when a peak correlation occurs at the output of the data-channel despreader **23**, of the received data channel signal. The second control signal is generated at a point later in time so that essentially noise is at the output of the data-channel despreader **23**. Techniques for extracting and generating a timing signal from a despread data channel signal are well known in the art.

The data-channel despreader **23** despreads the data channel signal embedded in the first spread-spectrum signal as a despread signal. If a pilot channel were not used or a pilot channel signal were not embedded in the first spread-spectrum signal, then the data-channel despreader **23** additionally can extract a timing signal or generate a timing signal from the despread data channel signal.

In response to the first control signal, the sample-and-hold circuit **24** samples the despread signal from the data-channel despreader **23** at a peak correlation time of the data channel signal to generate from the despread signal a signal level. In response to the second control signal, the sample-and-hold circuit **24** samples the despread signal at a non-peak correlation time of the data channel signal to generate from the despread signal a noise level. The first register **25**, also denoted as a noise register, stores the noise level. The second register **27**, also denoted as a signal register, stores the signal level.

The signal-to-noise ratio calculator **28** generates a signal-to-noise ratio from the signal level and the noise level.

Using the signal-to-noise ratio, the fuzzy-logic controller **29** can store the signal-to-noise ratio for later comparisons if desired. Also, using the signal-to-noise ratio, the fuzzy-logic controller **29** quantizes the signal-to-noise ratio to an N bit word and generates an N-bit control signal.

The base spread-spectrum transmitter **30** transmits the appropriate N-bit control signal from the fuzzy-logic controller **29**, every T_{APC} seconds, in a second spread-spectrum signal. The second spread-spectrum signal passes through the isolator **26** and is radiated by base antenna **31**.

FIG. 2 illustratively shows an alternative preferred embodiment of the base station. In FIG. 2, the base-controlling means is embodied as a matched filter acquisition circuit **44** and sample-and-hold controller **45**. The sample-and-hold means is shown as an analog-to-digital converter **42**. The base-despreading means is embodied as radio frequency (RF) circuitry **41** and matched filter **43**. The RF circuitry **41** is coupled through isolator **26** to antenna **31**, and through analog-to-digital converter **42** to matched filter **43**.

The base-SNR means is embodied as signal-to-noise ratio calculator **28**, data-power calculator **49**, noise-interference-power calculator **48**, data register **46** and noise register **47**. The signal-to-noise ratio calculator **28** is coupled through data power calculator **49** to data register **46**, and through noise-interference-power calculator **48** to noise register **47**. The data power calculator **49** is coupled to the noise interference power calculator **48**. The data register **46** and the noise register **47** are coupled to the output of the matched filter **43**, and are controlled by a timing signal from sample-and-hold controller **45**. The timing signal also controls analog-to-digital converter **42**.

The base-fuzzy means is shown as fuzzy-logic controller **29**, and the base-transmitting means is embodied as base spread-spectrum transmitter **30**. The fuzzy-logic controller **29** is coupled between the signal-to-noise ratio calculator **28** and the base spread-spectrum transmitter **30**. The base-spread-spectrum transmitter **30** is coupled through the isolator **26** to the base antenna **31**.

The base-spread-spectrum transmitter **30** of FIGS. **1** and **2** may include a spread-spectrum modulator **52**, a hard limiter **53** and an amplifier **55**. The hard limiter **53** is coupled between the spread-spectrum modulator **52** and the amplifier **55**. Other circuits, as is well known in the art, may be included with the base spread-spectrum transmitter **30**.

In FIG. 2, the antenna **31** receives and the first spread-spectrum signal and transmits the second spread-spectrum signal. In FIG. 1 or FIG. 2, separate transmit and receive antennas may be employed. Multiple antennas can be used at the transmitter and at the receiver facilities.

The radio frequency (RF) receive circuitry **41** receives the first spread-spectrum signal, amplifies the signal and then shifts this signal to baseband frequencies. The in-phase component and quadrature-phase component are determined or extracted from the first spread-spectrum signal at baseband previously set forth, the first spread-spectrum signal includes a data channel. For this embodiment, a pilot channel is not used, thus, timing signals are derived from the data channel.

The analog-to-digital converter **42** converts the in-phase and quadrature-phase components of the baseband signal from RF circuitry **41** into digital signals. Timing for analog-to-digital converter **42** is provided by the sample-and-hold controller **45**.

The output of the analog-to-digital converter **42** goes to the matched filter **43**, which is used for each data channel.

Only one data channel is shown, however multiple data channels would be used in practice. The matched filter **43** may be used to detect the pilot channel, if used, and to detect the data channel. Thus, in this preferred embodiment, by way of example, 8192 chips might be used in the pilot code; thus the pilot matched filter is L_p=8192 chips long. The data channel matched filter length L_d depends on the chip rate f_c and data rate f_d, i.e., $L_d=f_c/f_d$. The length L_d of chips of the data channel is usually much less than the length L_p of the chips of the pilot channel.

The matched filter acquisition circuit **44** includes the acquisition and tracking circuits used to ensure that any frequency offset and analog-to-digital sampling error is minimized. In addition, the matched filter acquisition circuit **44** determines at which time the matched filter **43** should be sampled to obtain the data output. The actual control of sampling is performed in the sample-and-hold controller **45**. The output data is stored in data register **46**.

If the matched filter **43** were sampled at times other than the correct time for a peak signal sampling, then the output obtained is approximately equal to the interference from all channels plus the thermal noise. This value is stored in the noise register **47**. The noise and interference power is calculated in the noise interference power calculator **48**.

It is well known that the despread output voltage V_0 (t) contained in data register **46** is approximately:

$$V_o(t) = \sqrt{P_1}\, d_1(t) + \sum_{i=2}^{N} d_i(t)\sqrt{P_i}\, \overline{g_i(t)g_1(t)} + \overline{n(t)g_1(t)}$$

where, for simplicity, assume that a first data channel is being measured; P_1 is the true power received from the first remote unit and $d_1\pm1$ is the bit transmitted; P_i is approximately equal to the power of the i^{th} remote unit, where $d_i\pm1$; n(t) is the thermal noise with power N as measured in the data bandwidth; processing gain (PG) is the number of chips per data bit; and K is the number of channels used.

Then from this equation, the term

$$\frac{\sum_{i=1}^{K}\sqrt{P_i}\, d_i + n}{\sqrt{PG}}$$

is the interference due to all data channels and noise. The total interference and noise ratio P_{I+N} is

$$P_{I+N} \simeq \frac{KP_{AVGE} + N}{PG}$$

Then the signal-to-noise ratio is

$$SNR = \frac{P_1}{KP_{AVGE} + N} PG$$

The value determined by noise interference power calculator **48** is approximately equal to P_{I+N} $(KP_{avge}+N)/PG$.

Subtracting P_{I+N} in the noise interference power calculator **48** from the power of V_o, which is stored in data register **46**, yields an approximation of the signal power P_1 in the first data channel. This subtraction is performed in the data-power calculator **49**, and the SNR is determined in the signal-to-noise ratio calculator **28**.

Fuzzy-Logic Controller

The fuzzy-logic spread-spectrum adaptive power control system functions to ensure that the signal-to-noise ratio (SNR) remains approximately constant even in the presence of a multitude of users operating in independently fading Rayleigh or Rician channels.

For example, if the signal-to-noise-ratio estimate were compared a threshold P_G equal to 6 dB, then the difference is e_n. One fuzzy-logic controller configuration, by way of example follows the rules:

Present State*	e_n(dB)	δ(dB)*	Next State*
000	>3	−2	000
	≦3	+1	001
001	>0	−1/2	010
	≦0	+1	011
010	>1	−1	100
	≦1	+1/2	101
011	>0	−1/2	110
	≦0	+1.5	111
100	>2	−1.5	000
	≦2	+0.5	001
101	>0	−1/2	010
	≦0	+1	011
110	>1	−1	100
	≦1	+1	101
111	>1	−1	110
	≦1	+2	111

*δ is the number of decibels (dB) over which the handset must change for this particular set of rules.

In the operation of this system, the present state consists of three bits, WXY. The base station sends 1 bit, Z, to the handset, so that the new state is XYZ. These state rules can also be illustrated by the state diagram of FIG. **3**.

FIG. **4** shows a signal fading in a typical Rayleigh channel and the received power from a handset. The fade bandwidth is 300 Hz. At 1900 symbols the fade is more than 20 dB deep and the handset cannot increase its power adequately; some of the fade is received at the base station. FIG. **5** shows a Rician fade and the received handset's signal at the base station.

A second example in which the base station updates its correction at one-half the rate used previously, but sends two bits rather than one bit, so that the effective bit rate is the same, is shown below in Table II. FIG. **6** is a state diagram of Table II.

		e_n = SNR − 6dB, dB		
Old State	e_n	$\lvert e_n\rvert$	δ(dB)	New State
00	>0	<1.5	−1	01
		≧1.5	−2	00
	≦0	<1	1	10
		≧1	3	11
01	>0	<2	−1	01
		≧2	−2	00
	≦0	<1	2	10
		≧1	3	11
10	>0	<2	−1	01
		≧2	−2	00
	≦0	<1	2	10
		≧1	3	11
11	>0	<2	−1	01
		<3	−2	00
		≧3	−3	10
	≦0	≦0	4	11

Thus, depending on the position in the state diagram and the transition from whatever state the remote unit is in, the base station can signal to the remote unit the amount to increase its power or decrease its power, depending on a previous state. These triggers for increasing and decreasing power levels come from the signal-to-noise ratio calculator **28**.

Remote Unit

At a remote unit, the remote-receiving means may be embodied as a remote-unit spread-spectrum receiver 11, as illustratively shown in FIG. 7. The remote-transmitting means may be embodied as a remote-unit spread-spectrum transmitter 13, and the remote-controlling means may be embodied as a transmitter controller 12. The transmitter controller 12 is coupled between the remote-unit spread-spectrum transmitter 13 and the remote-unit spread-spectrum receiver 11. The remote-unit spread-spectrum receiver 11 and the remote-unit spread-spectrum transmitter 13 are coupled to an isolator 16, which is coupled to a remote-unit antenna 15.

The remote-unit spread-spectrum receiver 11 receives the second spread-spectrum signal transmitted from the base station. The remote-unit spread-spectrum receiver 11 demodulates from the second spread-spectrum signal either of the first signal or the second signal, whichever is embedded in the second spread-spectrum signal, as a demodulated-control signal.

The transmitter controller 12, in response to the demodulated-control signal, adjusts a power level of the remote-unit spread-spectrum transmitter 13. The remote-unit spread-spectrum transmitter 13 transmits the first spread-spectrum signal. As mentioned previously, the first spread-spectrum signal optionally may have a pilot channel.

The present invention also includes a fuzzy-logic spread-spectrum adaptive power method which comprises the steps of receiving at a base station a first spread-spectrum signal which has a pilot channel and a data channel, and despreading a pilot channel signal embedded in the first spread-spectrum signal. The method also includes generating from the despread pilot channel signal a timing signal, and from the despread pilot channel signal, a first control signal and a second control signal. The use of a pilot channel is optional, and the timing signal alternatively may be obtained from the data channel signal.

The method further includes despreading at the base station a data channel signal embedded in the first spread-spectrum signal as a despread signal. Using the first control signal, the despread signal is sampled at a peak correlation time of the data channel signal to generate a signal level. In response to the second control signal, the despread signal is sampled at a non-peak correlation time of the data channel signal to generate a noise level. The method generates a signal-to-noise ratio from the signal level and the noise level, and compares, at the base station, the signal-to-noise ratio to a predetermined threshold. The signal-to-noise ratio is quantized to N bits depending on its relation to predetermined thresholds, and as a result the method generates an N-bit control signal. The method includes transmitting from the base station the N-bit control signal as part of a second spread-spectrum signal.

The method includes receiving, at a remote unit, the second spread-spectrum signal, and demodulating from the second spread-spectrum signal, the N-bit control signal which is embedded in the second spread-spectrum signal, as a demodulated-control signal. The method thereby adjusts at the remote unit, in response to the demodulated-control signal, a power level of the first spread-spectrum signal which is transmitted from the remote unit.

It will be apparent to those skilled in the art that various modifications can be made to the fuzzy-logic spread-spectrum adaptive power control system of the instant invention without departing from the scope or spirit of the invention, and it is intended that the present invention cover modifications and variations of the fuzzy-logic spread-spectrum adaptive power control system provided they come within the scope of the appended claims and their equivalents.

I claim:

1. A fuzzy-logic spread-spectrum system for adaptive power control from a base station comprising:

a base antenna for receiving a first spread-spectrum signal having a pilot channel and a data channel;

a pilot-channel despreader operatively coupled to said base antenna for despreading a pilot channel signal embedded in the first spread-spectrum signal and for generating from the despread pilot channel signal a timing signal;

a sample-and-hold controller, coupled to said pilot-channel despreader, responsive to the timing signal for generating a first control signal and a second control signal;

a data-channel despreader, coupled to said base antenna, for despreading a data channel signal embedded in the first spread-spectrum signal as a despread signal;

a sample-and-hold circuit, operatively coupled to said data-channel despreader and to said sample-and-hold controller, responsive to the first control signal for sampling the despread signal at a peak correlation time of the data channel signal to generate from the despread signal a signal level, and responsive to the second control signal, for sampling the despread signal at a non-peak correlation time of the data channel signal to generate from the despread signal a noise level;

a first register coupled to said sample-and-hold circuit for storing the signal level;

a second register coupled to said sample-and-hold circuit for storing the noise level;

a signal-to-noise ratio calculator coupled to said first register and to second register, for generating a signal-to-noise ratio from the signal level and the noise level;

a fuzzy-logic controller coupled to said signal-to-noise ratio calculator for comparing the signal-to-noise ratio to a predetermined set of thresholds to generate a control signal; and

a base spread-spectrum transmitter, coupled to said fuzzy-logic controller, for transmitting the control signal to a remote unit for adjusting a transmitter power level of said remote unit.

2. A fuzzy-logic spread-spectrum system for adaptive power control from a base station comprising:

a base antenna for receiving a spread-spectrum signal;

a sample-and-hold controller for generating a first control signal and a second control signal;

a data-channel despreader, coupled to said base antenna, for despreading a data signal embedded in the spread-spectrum signal as a despread signal;

a sample-and-hold circuit, operatively coupled to said data-channel despreader and to said sample-and-hold controller, responsive to the first control signal, for sampling the despread signal at a peak correlation time of the data signal to generate from the despread signal a signal level and, responsive to the second control signal, for sampling the despread signal at a non-peak correlation time of the data signal to generate from the despread signal a noise level;

a signal-to-noise ratio calculator coupled to said first register and to said second register, for generating a signal-to-noise ratio from the signal level and the noise level;

a fuzzy-logic controller, coupled said signal-to-noise ratio calculator, for comparing the signal-to-noise ratio to a predetermined threshold to generate a control signal; and

a base spread-spectrum transmitter, coupled to said fuzzy-logic controller, for transmitting the control signal to remote unit for adjusting a transmitter power level of said remote unit.

3. The fuzzy-logic spread-spectrum system as set forth in claim 2, further comprising:

a first register, coupled between said sample-and-hold circuit and said signal-to-noise ratio calculator, for storing the signal level; and

a second register, coupled between said sample-and-hold circuit and said signal-to-noise ratio calculator, for storing the noise level.

4. The fuzzy-logic spread-spectrum system as set forth in claim 2, said remote unit comprising:

a remote-unit antenna;

a remote-unit spread-spectrum receiver coupled to said remote-unit antenna for receiving the control signal;

a remote-unit spread-spectrum transmitter coupled to said remote-unit antenna for transmitting the spread-spectrum signal; and

a transmitter controller coupled between said remote-unit spread-spectrum receiver and said remote-unit spread-spectrum transmitter, responsive to the control signal, for adjusting the transmitter power level of said remote-unit spread-spectrum transmitter.

5. The fuzzy-logic spread-spectrum system as set forth in claim 2, further comprising:

a pilot-channel despreader, coupled to said base antenna, for despreading a pilot signal embedded in the spread-spectrum signal and for generating, from the despread pilot signal, a timing signal;

said sample-and-hold controller generating, responsive to the timing signal, the first control signal and the second control signal.

6. A method for adaptive power control of a spread-spectrum signal using fuzzy-logic at a base station, comprising the steps of:

receiving, at the base station, a spread-spectrum signal;

generating a first control signal and a second control signal;

despreading a data signal embedded in the spread-spectrum signal as a despread signal;

sampling, in response to the first control signal, the despread signal at a peak correlation time of the data signal to generate from the despread signal a signal level;

sampling, in response to the second control signal, the despread signal at a non-peak correlation time of the data signal to generate from the despread signal a noise level;

generating a signal-to-noise ratio from the signal level and the noise level;

comparing the signal-to-noise ratio to a predetermined threshold;

generating, responsive to a relationship between the signal-to-noise ratio and the predetermined threshold, a control signal; and

transmitting the control signal to a remote unit for adjusting, at the remote unit and responsive to the control signal, a transmitter power level of said remote unit.

7. The method as set forth in claim 6, further comprising the steps of:

despreading a pilot signal embedded in the spread-spectrum signal to generate a timing signal; and

generating, using the timing signal, the first control signal and the second control signal.

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